

PDF hosted at the Radboud Repository of the Radboud University Nijmegen

The following full text is a publisher's version.

For additional information about this publication click this link.

<http://hdl.handle.net/2066/161330>

Please be advised that this information was generated on 2017-12-06 and may be subject to change.

Search for supersymmetry in a final state containing two photons and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions at the LHC using the ATLAS detector

ATLAS Collaboration*

CERN, 1211 Geneva 23, Switzerland

Received: 30 June 2016 / Accepted: 30 August 2016 / Published online: 24 September 2016
 © The Author(s) 2016. This article is published with open access at Springerlink.com

Abstract A search has been made for supersymmetry in a final state containing two photons and missing transverse momentum using the ATLAS detector at the Large Hadron Collider. The search makes use of 3.2 fb^{-1} of proton-proton collision data collected at a centre-of-mass energy of 13 TeV in 2015. Using a combination of data-driven and Monte-Carlo-based approaches, the Standard Model background is estimated to be $0.27^{+0.22}_{-0.10}$ events. No events are observed in the signal region; considering the expected background and its uncertainty, this observation implies a model-independent 95 % CL upper limit of 0.93 fb (3.0 events) on the visible cross section due to physics beyond the Standard Model. In the context of a generalized model of gauge-mediated supersymmetry breaking with a bino-like next-to-lightest supersymmetric particle, this leads to a lower limit of 1650 GeV on the mass of a degenerate octet of gluino states, independent of the mass of the lighter bino-like neutralino.

Contents

1 Introduction	1
2 Samples of simulated processes	2
3 ATLAS detector	2
4 Event reconstruction	3
5 Event selection	4
6 Background estimation	5
7 Signal efficiencies and uncertainties	6
8 Results	7
9 Conclusion	8
References	9

1 Introduction

This paper presents a search for signatures of supersymmetry in events containing two energetic isolated photons and large missing transverse momentum (with magnitude

denoted $E_{\text{T}}^{\text{miss}}$) in 3.2 fb^{-1} of proton–proton (pp) collision data at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector at the Large Hadron Collider (LHC) in 2015. The results are interpreted in the context of general gauge mediation (GGM) [1, 2] models that include the production of supersymmetric partners of Standard Model (SM) particles that possess color charge. In all models of GGM, the lightest supersymmetric particle (LSP) is the gravitino \tilde{G} (the partner of the hypothetical quantum of the gravitational field), with a mass significantly less than 1 GeV. In the GGM model considered here, the decay of the supersymmetric states produced in pp collisions would proceed through the next-to-lightest supersymmetric particle (NLSP), which would then decay to the \tilde{G} LSP and one or more SM particles, with a high probability of decay into $\gamma + \tilde{G}$. All accessible supersymmetric states with the exception of the \tilde{G} are assumed to be short-lived, leading to prompt production of SM particles that would be observed in the ATLAS detector. These results extend those of prior studies with 8 TeV collision data from Run 1 by the ATLAS [3] and CMS [4] experiments.

Supersymmetry (SUSY) [5–10] introduces a symmetry between fermions and bosons, resulting in a SUSY particle (sparticle) with identical quantum numbers, with the exception of a difference of half a unit of spin relative to its corresponding SM partner. If SUSY were an exact symmetry of nature, each sparticle would have a mass equal to that of its SM partner. Since no sparticles have yet been observed, SUSY would have to be a broken symmetry. Assuming R -parity conservation [11], sparticles are produced in pairs. These would then decay through cascades involving other sparticles until the stable, undetectable LSP is produced, leading to a final state with significant $E_{\text{T}}^{\text{miss}}$.

Experimental signatures of gauge-mediated supersymmetry-breaking models [12–14] are largely determined by the nature of the NLSP. For GGM, the NLSP is often formed from an admixture of any of the SUSY partners of the electroweak gauge and Higgs boson states. In this study

* e-mail: atlas.publications@cern.ch

the NLSP, assumed to be electrically neutral and purely bino-like (the SUSY partner of the SM U(1) gauge boson), is the lightest gaugino state $\tilde{\chi}_1^0$. In this case, the final decay in each of the two cascades in a GGM event would be predominantly $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$, leading to final states with $\gamma\gamma + E_T^{\text{miss}}$.

In addition to the bino-like $\tilde{\chi}_1^0$ NLSP, a degenerate octet of gluinos (the SUSY partner of the SM gluon) is taken to be potentially accessible with 13 TeV pp collisions. Both the gluino and $\tilde{\chi}_1^0$ masses are considered to be free parameters, with the $\tilde{\chi}_1^0$ mass constrained to be less than that of the gluino. All other SUSY masses are set to values that preclude their production in 13 TeV pp collisions. This results in a SUSY production process that proceeds through the creation of pairs of gluino states, each of which subsequently decays via a virtual squark (the 12 squark flavour/chirality eigenstates are taken to be fully degenerate) to a quark–antiquark pair plus the NLSP neutralino. Additional SM objects (jets, leptons, photons) may be produced in these cascades. The $\tilde{\chi}_1^0$ branching fraction to $\gamma + \tilde{G}$ is 100 % for $m_{\tilde{\chi}_1^0} \rightarrow 0$ and approaches $\cos^2 \theta_W$ for $m_{\tilde{\chi}_1^0} \gg m_Z$, with the remainder of the $\tilde{\chi}_1^0$ sample decaying to $Z + \tilde{G}$. For all $\tilde{\chi}_1^0$ masses, then, the branching fraction is dominated by the photonic decay, leading to the diphoton-plus- E_T^{miss} signature. For this model with a bino-like NLSP, a typical production and decay channel for strong (gluino) production is exhibited in Fig. 1. Finally, it should be noted that the phenomenology relevant to this search has a negligible dependence on the ratio $\tan \beta$ of the two SUSY Higgs-doublet vacuum expectation values; for this analysis $\tan \beta$ is set to 1.5.

2 Samples of simulated processes

For the GGM models under study, the SUSY mass spectra and branching fractions are calculated using SUSPECT 2.41 [15] and SDECAY 1.3b [16], respectively, inside the package

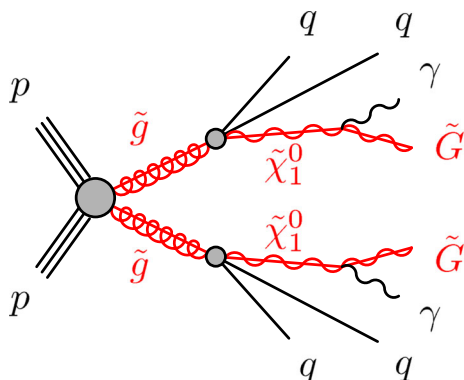


Fig. 1 Typical production and decay-chain processes for the gluino-pair production GGM model for which the NLSP is a bino-like neutralino

SUSY-HIT 1.3 [17]. The Monte Carlo (MC) SUSY signal samples are produced using Herwig++ 2.7.1 [18] with CTEQ6L1 parton distribution functions (PDFs) [19]. Signal cross sections are calculated to next-to-leading order (NLO) in the strong coupling constant, including, for the case of strong production, the resummation of soft gluon emission at next-to-leading-logarithmic accuracy (NLO+NLL) [20–24]. The nominal cross section and its uncertainty are taken from an envelope of cross-section predictions using different PDF sets and factorization and renormalization scales [25]. At fixed centre-of-mass energy, SUSY production cross sections decrease rapidly with increasing SUSY particle mass. At $\sqrt{s} = 13$ TeV, the gluino-pair production cross section is approximately 25 fb for a gluino mass of 1.4 TeV and falls to below 1 fb for a gluino mass of 2.0 TeV.

While most of the backgrounds to the GGM models under examination are estimated through the use of control samples selected from data, as described below, the extrapolation from control regions (CRs) to the signal region (SR) depends on simulated samples, as do the optimization studies. Diphoton, photon+jet, $W\gamma$, $Z\gamma$, $W\gamma\gamma$ and $Z\gamma\gamma$ SM processes are generated using the SHERPA 2.1.1 simulation package [26], making use of the CT10 PDFs [27]. The matrix elements are calculated with up to three parton emissions at leading order (four in the case of photon+jet samples) and merged with the SHERPA parton shower [28] using the ME+PS@LO prescription [29]. The $t\bar{t}\gamma$ process is generated using MadGraph5_aMC@NLO [30] with the CTEQ6L1 PDFs [19], in conjunction with PYTHIA 8.186 [31] with the NNPDF2.3 LO PDF set [32,33] and the A14 set [34] of tuned parameters.

All simulated samples are processed with a full ATLAS detector simulation [35] based on GEANT4 [36]. The effect of additional pp interactions per bunch crossing (“pile-up”) as a function of the instantaneous luminosity is taken into account by overlaying simulated minimum-bias events according to the observed distribution of the number of pile-up interactions in data, with an average of 13 interactions per event.

3 ATLAS detector

The ATLAS experiment records pp collision data with a multipurpose detector [37] that has a forward-backward symmetric cylindrical geometry and nearly 4π solid angle coverage. Closest to the beam line are solid-state tracking devices comprising layers of silicon-based pixel and strip detectors covering $|\eta| < 2.5$ and straw-tube detectors covering $|\eta| < 2.0$, located inside a thin superconducting solenoid that provides a 2T magnetic field. Outside of this “inner detector”, fine-grained lead/liquid-argon electromagnetic (EM) calorimeters provide coverage over $|\eta| < 3.2$ for the measurement of the energy and direction of electrons and photons. A pre-

sampler, covering $|\eta| < 1.8$, is used to correct for energy lost upstream of the EM calorimeter. A steel/scintillator-tile hadronic calorimeter covers the region $|\eta| < 1.7$, while a copper/liquid-argon medium is used for hadronic calorimeters in the end cap region $1.5 < |\eta| < 3.2$. In the forward region $3.2 < |\eta| < 4.9$ liquid-argon calorimeters with copper and tungsten absorbers measure the electromagnetic and hadronic energy. A muon spectrometer consisting of three superconducting toroidal magnet systems, each comprising eight toroidal coils, tracking chambers, and detectors for triggering, surrounds the calorimeter system. The muon system reconstructs penetrating tracks over a range $|\eta| < 2.7$ and provides input to the trigger system over a range $|\eta| < 2.4$. A two-level trigger system [38] is used to select events. The first-level trigger is implemented in hardware and uses a subset of the detector information to reduce the accepted rate to less than 100 kHz. This is followed by a software-based ‘high-level’ trigger (HLT) that reduces the recorded event rate to approximately 1 kHz.

4 Event reconstruction

Primary vertices are formed from sets of two or more tracks, each with transverse momentum $p_T^{\text{track}} > 400$ MeV, that are mutually consistent with having originated at the same three-dimensional point within the luminous region of the colliding proton beams. When more than one such primary vertex is found, the vertex with the largest sum of the squared transverse momenta of the associated tracks is chosen.

Electron candidates are reconstructed from EM calorimeter energy clusters consistent in transverse shape and longitudinal development with having arisen from the impact of an electromagnetic particle (electron or photon) upon the face of the calorimeter. For the object to be considered an electron, it is required to match a track identified by a reconstruction algorithm optimized for recognizing charged particles with a high probability of bremsstrahlung [39]. The energy of the electron candidate is determined from the EM cluster, while its direction is determined from the associated reconstructed track. Electron candidates are required to have $p_T > 25$ GeV and $|\eta| < 2.37$, and to be outside the transition region $1.37 < |\eta| < 1.52$ between the central and forward portions of the EM calorimeter. Finally, the electron track is required to be consistent with originating from the primary vertex in both the $r - z$ and $r - \phi$ planes. Further details of the reconstruction of electrons can be found in Refs. [40, 41].

Electromagnetic clusters are classified as photon candidates provided that they either have no matched track or have one or more matched tracks consistent with having arisen from a photon conversion. Based on the characteristics of the longitudinal and transverse shower development in the EM calorimeter, photons are classified as “loose” or

“tight”, with the tight requirements leading to a more pure but less efficient selection of photons relative to that of the loose requirements [42]. Photon candidates are required to have $p_T > 25$ GeV, to be within $|\eta| < 2.37$, and to be outside the transition region $1.37 < |\eta| < 1.52$. Additionally, an isolation requirement is imposed: after correcting for contributions from pile-up and the deposition ascribed to the photon itself, the energy within a cone of $\Delta R = 0.4$ around the cluster barycentre is required to be less than $2.45 \text{ GeV} + 0.022 \times p_T^\gamma$, where p_T^γ is the transverse momentum of the cluster. In the case that an EM calorimeter deposition identified as a photon overlaps the cluster of an identified electron within a cone of $\Delta R = 0.4$, the photon candidate is discarded and the electron candidate is retained. Further details of the reconstruction of photons can be found in Ref. [42].

Muon candidates make use of reconstructed tracks from the inner detector as well as information from the muon system [43]. Muons are required to be either “combined”, for which the muon is reconstructed independently in both the muon spectrometer and the inner detector and then combined, or “segment-tagged”, for which the muon spectrometer is used to tag tracks as muons, without requiring a fully reconstructed candidate in the muon spectrometer. Muons are required to have $p_T > 25$ GeV and $|\eta| < 2.7$, with the muon track required to be consistent with originating from the primary vertex in both the $r - z$ and $r - \phi$ planes.

Jets are reconstructed from three-dimensional energy clusters [44] in the electromagnetic and hadronic calorimeters using the anti- k_t algorithm [45] with a radius parameter $R = 0.4$. Each cluster is calibrated to the electromagnetic scale prior to jet reconstruction. The reconstructed jets are then calibrated to particle level by the application of a jet energy scale derived from simulation and *in situ* corrections based on 8 TeV data [46, 47]. In addition, the expected average energy contribution from pile-up clusters is subtracted using a factor dependent on the jet area [46]. Track-based selection requirements are applied to reject jets with $p_T < 60$ GeV and $|\eta| < 2.4$ that originate from pile-up interactions [48]. Once calibrated, jets are required to have $p_T > 40$ GeV and $|\eta| < 2.8$.

To resolve the ambiguity that arises when a photon is also reconstructed as a jet, if a jet and a photon are reconstructed within an angular distance $\Delta R = 0.4$ of one another, the photon is retained and the jet is discarded. If a jet and an electron are reconstructed within an angular distance $\Delta R = 0.2$ of one another, the electron is retained and the jet is discarded; if $0.2 < \Delta R < 0.4$ then the jet is retained and the electron is discarded. Finally, in order to suppress the reconstruction of muons arising from showers induced by jets, if a jet and a muon are found with $\Delta R < 0.4$ the jet is retained and the muon is discarded.

The missing transverse momentum $\mathbf{p}_T^{\text{miss}}$ is defined as the negative vector sum of the p_T of all reconstructed physics objects in the event, with an extra term added to account for soft energy in the event that is not associated with any of the objects. This “ E_T^{miss} soft term” is calculated from inner-detector tracks with p_T above 400 MeV matched to the primary vertex to make it less dependent upon pile-up contamination [49, 50]. The scalar observable E_T^{miss} is defined to be the magnitude of the resulting $\mathbf{p}_T^{\text{miss}}$ vector.

Several additional observables are defined to help in the discrimination of SM backgrounds from potential GGM signals. The total visible transverse energy, H_T , is calculated as the scalar sum of the transverse momenta of the reconstructed photons and any additional leptons and jets in the event. The “effective mass”, m_{eff} , is defined as the scalar sum of H_T and E_T^{miss} . The minimum jet– $\mathbf{p}_T^{\text{miss}}$ separation, $\Delta\phi_{\text{min}}(\text{jet}, \mathbf{p}_T^{\text{miss}})$, is defined as the minimum azimuthal angle between the missing transverse momentum vector and the two leading (highest- p_T) jets with $p_T > 75$ GeV in the event, if they are present. If no such jets exist, no requirement is placed on this observable.

5 Event selection

The data sample is selected by a HLT trigger requiring the presence of two loose photons, each with p_T greater than 50 GeV. Offline, two tight photons with $p_T > 75$ GeV are required. In order to ensure that E_T^{miss} is measured well, events are removed from the data sample if they contain jets likely to be produced by beam backgrounds, cosmic rays or detector noise [51].

To exploit the significant undetectable transverse momentum carried away by the gravitinos, a requirement on E_T^{miss} is imposed on the diphoton event sample. To take advantage of the high production energy scale associated with signal events near the expected reach of the analysis, an additional requirement on m_{eff} is applied. To further ensure the accurate reconstruction of E_T^{miss} and to suppress backgrounds associated with the mismeasurement of hadronic jets, a requirement of $\Delta\phi_{\text{min}}(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.5$ is imposed. Figure 2 shows the E_T^{miss} and m_{eff} distributions of the diphoton sample after the application of requirements of $p_T^\gamma > 75$ GeV on each selected photon and of $\Delta\phi_{\text{min}}(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.5$, but with no requirements yet imposed on E_T^{miss} and m_{eff} . Also shown are the expected contributions from SM processes, estimated using the combination of Monte Carlo and data-driven estimates discussed in Sect. 6.

As discussed in Sect. 1, the GGM signal space is parameterized by the masses of the gluino ($m_{\tilde{g}}$) and bino-like NLSP ($m_{\tilde{\chi}_1^0}$). The sensitivity of this analysis was optimized for two signal scenarios near the expected reach in $m_{\tilde{g}}$: high and low neutralino-mass benchmark points were chosen with $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 1300)$ GeV and $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 100)$ GeV, respectively.

Based on background estimates derived from the MC samples described in Sect. 2, the selection requirements were optimized as a function of E_T^{miss} , m_{eff} and p_T^γ by maximizing the expected discovery sensitivity of the analysis, for each of the two signal benchmark points. The selected values of the minimum requirements on all three optimization parameters were found to be very similar for the low and high neutralino-

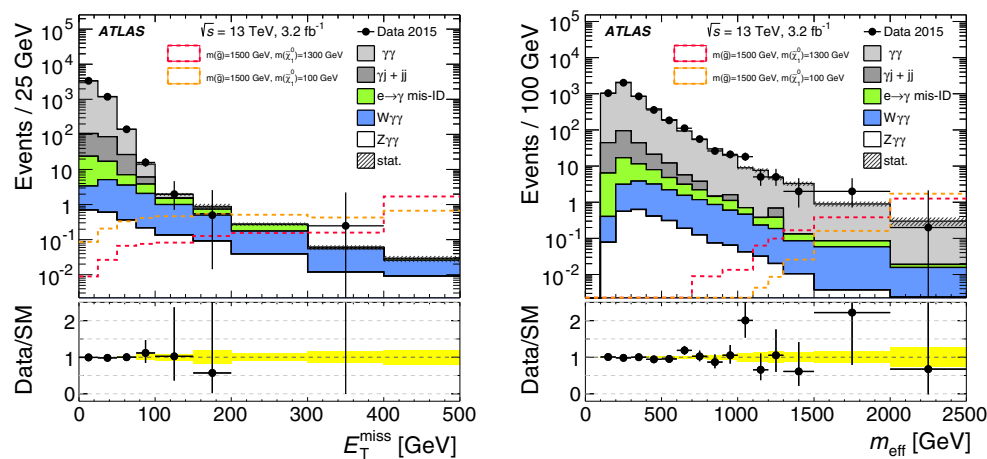


Fig. 2 Distributions of E_T^{miss} (left) and m_{eff} (right) for the diphoton sample after the application of requirements of $p_T^\gamma > 75$ GeV on each selected photon and of $\Delta\phi_{\text{min}}(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.5$, but with no requirements imposed on E_T^{miss} and m_{eff} . The expected contributions from SM processes are estimated using the combination of Monte Carlo and data-driven estimates discussed in Sect. 6. Uncertainties (shaded bands for MC simulation, error bars for data) are statistical only. The yellow

band represents the uncertainty in the data/SM ratio that arises from the statistical limitations of the estimates of the various expected sources of SM background. Also shown are the expected contributions from the GGM signal for the two benchmark points, $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 1300)$ GeV and $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 100)$ GeV. The final bin of each plot includes the ‘overflow’ contribution that lies above the nominal upper range of the plot

Table 1 Requirements defining the signal region (SR) and the $W\gamma\gamma$ CR referred to in Sect. 6

SR	$W\gamma\gamma$ CR
2 Tight photons with $p_T > 75$ GeV	2 Tight photons with $p_T > 50$ GeV
$\Delta\phi_{\min}(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.5$	1 e or μ with $p_T > 25$ GeV
$E_T^{\text{miss}} > 175$ GeV	$50 < E_T^{\text{miss}} < 175$ GeV
$m_{\text{eff}} > 1500$ GeV	$N(\text{jets}) < 3$
	$m_{e\gamma} \notin 83\text{--}97$ GeV

mass benchmark points, leading to the definition of a single signal region (SR). The selection requirements for this SR are shown in Table 1.

6 Background estimation

Processes that contribute to the Standard Model background of diphoton final states can be divided into three primary components. The largest contribution to the inclusive diphoton spectrum is the “QCD background”, which can be further divided into a contribution from two real photons produced in association with jets, and a “jet-faking-photon” contribution arising from γ +jet and multijet events for which one or both reconstructed photons are faked by a jet, typically by producing a $\pi^0 \rightarrow \gamma\gamma$ decay that is misidentified as a prompt photon. An “electron-faking-photon background” arises predominantly from W , Z , and $t\bar{t}$ events, possibly accompanied by additional jets and/or photons, for which an electron is misidentified as a photon. Electron-to-photon misidentification is due primarily to instances for which an electron radiates a high-momentum photon as it traverses the material of the ATLAS inner detector. Last, an “irreducible background” arises from $W\gamma\gamma$ and $Z\gamma\gamma$ events. These backgrounds are estimated with a combination of data-driven and simulation-based methods described as follows.

The component of the QCD background arising from real diphoton events ($\gamma\gamma$) is estimated directly from diphoton MC events, rescaled as function of E_T^{miss} and the number of selected jets to match the respective distributions for the inclusive diphoton sample in the range $E_T^{\text{miss}} < 100$ GeV. While this background dominates the inclusive diphoton sample, it is very steeply falling in E_T^{miss} , making it small relative to backgrounds with real E_T^{miss} for $E_T^{\text{miss}} \gtrsim 100$ GeV, independent of the reweighting.

The component of the QCD background arising from jets faking photons and the background arising from electrons faking photons are both estimated with a data-driven “fake-factor” method, for which events in data samples enriched in

the background of interest are weighted by factors parameterizing the misidentification rate.

To estimate the jet-faking-photon fake-factor, the jet-faking-photon background is enriched by using an inverted isolation requirement, selecting events only if they contain one or more non-isolated photons. The relative probability of an energy cluster being reconstructed as an isolated, rather than non-isolated, photon is known as the photon-isolation fake factor, and is measured in an orthogonal “non-tight” sample of photons. The selection of this sample requires that all the tight photon identification requirements be satisfied, with the exception that at least one of the requirements on the calorimeter variables defined only with the first (strip) layer of the electromagnetic calorimeter fails. This leads to a sample enriched in identified (non-tight) photons that are actually π^0 s within jets. The correlation between the isolation variable and the photon identification requirements was found to be small and to have no significant impact on the estimation of the jet-faking-photon fake-factor. The fake factors depend upon p_T and η , and vary between 10 and 30 %. The jet-faking photon background is then estimated by weighting events with non-isolated photons by the applicable photon-isolation fake factor.

The electron-faking-photon background is estimated with a similar fake-factor method. For this case, the electron-faking-photon background is enriched by selecting events with a reconstructed electron instead of a second photon. Fake factors for electrons being misidentified as photons are then measured by comparing the ratio of reconstructed $e\gamma$ to ee events arising from Z bosons decaying to electron-positron pairs, selected within the mass range of 75–105 GeV. The electron-faking-photon background is then estimated by weighting selected $e\gamma$ events by their corresponding fake factors, which are typically a few percent.

The irreducible background from $W\gamma\gamma$ events is estimated with MC simulation; however, because it is a potentially dominant background contribution, the overall normalization is derived in a $\ell\gamma\gamma$ control region ($W\gamma\gamma$ CR) as follows. Events in the $W\gamma\gamma$ CR are required to have two tight, isolated photons with $p_T > 50$ GeV, and exactly one selected lepton (electron or muon) with $p_T > 25$ GeV. As with the SR, events are required to have $\Delta\phi_{\min}(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.5$, so that the direction of the missing transverse momentum vector is not aligned with that of any high- p_T jet. To ensure that the control sample has no overlap with the signal region, events are discarded if $E_T^{\text{miss}} > 175$ GeV. While these requirements target $W\gamma\gamma$ production, they also are expected to select appreciable backgrounds from $t\bar{t}\gamma$, $Z\gamma$ and $Z\gamma\gamma$ events, and thus additional requirements are applied. To suppress $t\bar{t}\gamma$ contributions to the $W\gamma\gamma$ CR, events are discarded if they contain more than two selected jets. To suppress $Z\gamma$ contributions, events are discarded if there is an $e\gamma$ pair in the events with $83 < m_{e\gamma} < 97$ GeV. Finally, to suppress $Z\gamma\gamma$

contributions, events with $E_T^{\text{miss}} < 50$ GeV are discarded. The event selection requirements for the $W\gamma\gamma$ CR are summarized in Table 1. A total of seven events are observed in this $W\gamma\gamma$ control region, of which 1.6 are expected to arise from sources other than $W\gamma\gamma$ production. The MC expectation for the $W\gamma\gamma$ process is 1.9 events, leading to a $W\gamma\gamma$ scale factor of 2.9 ± 1.4 , assuming that no GGM signal events contaminate the $W\gamma\gamma$ CR. This scale factor is consistent with that of the corresponding $\sqrt{s} = 8$ TeV analysis [3], and is reconciled by a large and uncertain NLO correction to the $W\gamma\gamma$ production cross section that depends strongly upon the momentum of the $W\gamma\gamma$ system [52]. When setting limits on specific signal models, a simultaneous fit to the control region and the signal region is performed, allowing both the signal and $W\gamma\gamma$ contributions to float to their best-fit values.

Last, the irreducible background from $Z(\rightarrow \nu\nu)\gamma\gamma$ events, the only background without a data-derived normalization, is estimated with simulation and found to be 0.02 events. A $\pm 100\%$ uncertainty is conservatively applied to account for modelling uncertainties [53].

A summary of the background contributions to the signal region is presented in Table 2. The QCD background can be traced to a few hundredths of an event at high E_T^{miss} and high m_{eff} , but no events are observed for either the diphoton Monte Carlo or the jet-faking-photon control sample when the full signal region requirements are applied. Relaxing the m_{eff} requirement, and using a conservative extrapolation of the expected QCD background as a function of m_{eff} , the combined QCD background is estimated to be $0.05^{+0.20}_{-0.05}$ events. The estimate of the electron-faking-photon background is established by the presence of two $e\gamma$ events in the background model passing the SR requirements, yielding a background estimate of 0.03 ± 0.02 events after application of the fake-factor weights. Summing all background contributions, a total of $0.27^{+0.22}_{-0.10}$ SM events are expected in the SR,

with the largest contribution, 0.17 ± 0.08 events, expected to arise from $W\gamma\gamma$ production. The background modelling was found to agree well in several validation regions, including the inclusive high- p_T diphoton sample, as well as event selections with relaxed m_{eff} and E_T^{miss} requirements relative to those of the SR.

7 Signal efficiencies and uncertainties

GGM signal acceptances and efficiencies are estimated using MC simulation for each simulated point in the gluino–bino parameter space, and vary significantly across this space due to variations in the photon p_T , E_T^{miss} , and m_{eff} spectra. For example, for a gluino mass of 1600 GeV, the acceptance-times-efficiency product varies between 14 and 28 %, reaching a minimum as the NLSP mass approaches the Z boson mass, below which the photonic branching fraction of the NLSP rises to unity. Table 3 summarizes the contributions to the systematic uncertainty of the signal acceptance-times-efficiency, which are discussed below.

Making use of a bootstrap method [54], the efficiency of the diphoton trigger is determined to be greater than 99 %, with an uncertainty of less than 1 %. The uncertainty in the integrated luminosity is $\pm 2.1\%$. It is derived, following a methodology similar to that detailed in Ref. [55], from a calibration of the luminosity scale using x – y beam-separation scans performed in August 2015.

The reconstruction and identification efficiency for tight, isolated photons is estimated with complementary data-driven methods [42]. Photons selected kinematically as originating from radiative decays of a Z boson ($Z \rightarrow \ell^+\ell^-\gamma$

Table 2 Summary of background estimates by source, and total combined background, in the signal region. The uncertainties shown include the total statistical and systematic uncertainty. Also shown is the expected number of signal events for the benchmark points $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 100)$ and $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 1300)$, where all masses are in GeV

Source	Number of events
QCD ($\gamma\gamma, \gamma j, jj$)	$0.05^{+0.20}_{-0.05}$
$e \rightarrow \gamma$ fakes	0.03 ± 0.02
$W\gamma\gamma$	0.17 ± 0.08
$Z\gamma\gamma$	0.02 ± 0.02
Sum	$0.27^{+0.22}_{-0.10}$
$(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 100)$	7.0
$(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (1500, 1300)$	8.0

Table 3 Summary of individual and total contributions to the systematic uncertainty of the signal acceptance-times-efficiency. Relative uncertainties are shown in percent, and as the average over the full range of the $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0})$ grid. Because the individual contributions are averaged over the grid only for that particular source, the average total uncertainty is not exactly equal to the quadrature sum of the individual average uncertainties

Source of systematic uncertainty	Value
Luminosity (%)	2.1
Photon identification (%)	3.0
Photon energy scale (%)	0.2
Photon energy resolution (%)	0.2
Jet energy scale (%)	0.4
Jet energy resolution (%)	0.3
E_T^{miss} soft term (%)	<0.1
Pile-up uncertainty (%)	1.8
MC statistics (%)	2.3
Total experimental uncert. (%)	4.7

events) are used to study the photon reconstruction efficiency as a function of p_T and η . Independent measurements making use of a tag-and-probe approach with $Z \rightarrow ee$ events, with one of the electrons used to probe the calorimeter response to electromagnetic depositions, also provide information about the photon reconstruction efficiency. For photons with $p_T > 75$ GeV, the identification efficiency varies between 93 and 99 %, depending on the values of the photon p_T and $|\eta|$ and whether the photon converted in the inner detector. The uncertainty also depends upon these factors, and is generally no more than a few percent.

Uncertainties in the photon and jet energy scales lead to uncertainties in the signal acceptance-times-efficiency that vary across the GGM parameter space, and contribute the dominant source of acceptance-times-efficiency uncertainty in certain regions of the parameter space. The photon energy scale is determined using samples of $Z \rightarrow ee$ and $J/\psi \rightarrow ee$ events [56]. The jet-energy scale uncertainty is constrained from an assessment of the effect of uncertainties in the modelling of jet properties and by varying the response to differing jet flavour composition in MC simulations, as well as from *in situ* measurements with 8 TeV dijet data [46,47].

Uncertainties in the values of whole-event observables, such as E_T^{miss} and m_{eff} , arise from uncertainties in the energy of the underlying objects from which they are constructed. Uncertainties in the E_T^{miss} soft term due to uncertainties in hadronic fragmentation, detector material modeling and energy scale were found to introduce an uncertainty of less than 0.1 % in the signal acceptance-times-efficiency. The uncertainty due to pile-up is estimated by varying the mean of the distribution of the number of interactions per bunch crossing overlaid in the simulation by ± 11 %.

Including the contribution from the statistical limitations of the MC samples used to model the GGM parameter space, the quadrature sum of the individual systematic uncertainties in the signal reconstruction efficiency is, on average, about 4 %. Adding the uncertainty in the integrated luminosity gives a total systematic uncertainty of about 5 %.

8 Results

An accounting of the numbers of events observed in the SR after the successive application of the selection requirements is shown in Table 4 along with the size of the expected SM background. After the full selection is applied, no events are observed in the SR, to be compared to an expectation of $0.27^{+0.22}_{-0.10}$ SM events.

Based on the observation of zero events in the SR and the magnitude of the estimated SM background expectation and uncertainty, an upper limit is set on the number

Table 4 Numbers of events observed in the SR after the successive application of the selection requirements, as well as the size of the expected SM background

Requirement	Number of events
Two photons, $p_T^\gamma > 75$	4982
$\Delta\phi_{\text{min}}(\text{jet}, p_T^{\text{miss}}) > 0.5$	4724
$m_{\text{eff}} > 1500$ GeV	1
$E_T^{\text{miss}} > 175$ GeV	0
Expected SM background	$0.27^{+0.22}_{-0.10}$

of events from any scenario of physics beyond the SM, using the profile likelihood and CL_s prescriptions [57]. The various sources of experimental uncertainty, including those in the background expectation, are treated as Gaussian-distributed nuisance parameters in the likelihood definition. Assuming that no events due to physical processes beyond those of the SM populate the $\ell\gamma\gamma$ CR used to estimate the $W(\rightarrow \ell\nu) + \gamma\gamma$ background, the observed 95 % confidence-level (CL) upper limit on the number of non-SM events in the SR is found to be 3.0. Taking into account the integrated luminosity of 3.2 fb^{-1} , this number-of-event limit translates into a 95 % CL upper limit on the visible cross section for new physics, defined by the product of cross section, branching fraction, acceptance and efficiency, of 0.93 fb.

By considering, in addition, the value and uncertainty of the acceptance-times-efficiency of the selection requirements associated with the SR, as well as the NLO (+NLL) GGM cross section [20–24], which varies steeply with gluino mass, 95 % CL lower limits may be set on the mass of the gluino as a function of the mass of the lighter bino-like neutralino, in the context of the GGM scenario described in Sect. 1. The resulting observed limit on the gluino mass is exhibited, as a function of neutralino mass, in Fig. 3. For the purpose of establishing these model-dependent limits, the $W(\rightarrow \ell\nu) + \gamma\gamma$ background estimate and the limit on the possible number of events from new physics are extracted from a simultaneous fit to the SR and $W(\rightarrow \ell\nu) + \gamma\gamma$ control region, although for a gluino mass in the range of the observed limit the signal contamination in the $W(\rightarrow \ell\nu) + \gamma\gamma$ control sample is less than 0.03 events for any value of the neutralino mass. Also shown for this figure is the expected limit, including its statistical and background uncertainty range, as well as observed limits for a SUSY model cross section ± 1 standard deviation of theoretical uncertainty from its central value. Because the background expectation is close to zero and no events are observed in data, the expected and observed limits nearly overlap. The observed lower limit on the gluino mass is observed to be roughly independent of neutralino mass, reaching a minimum value of approximately 1650 GeV at a neutralino mass of 250 GeV. Within the context of this model,

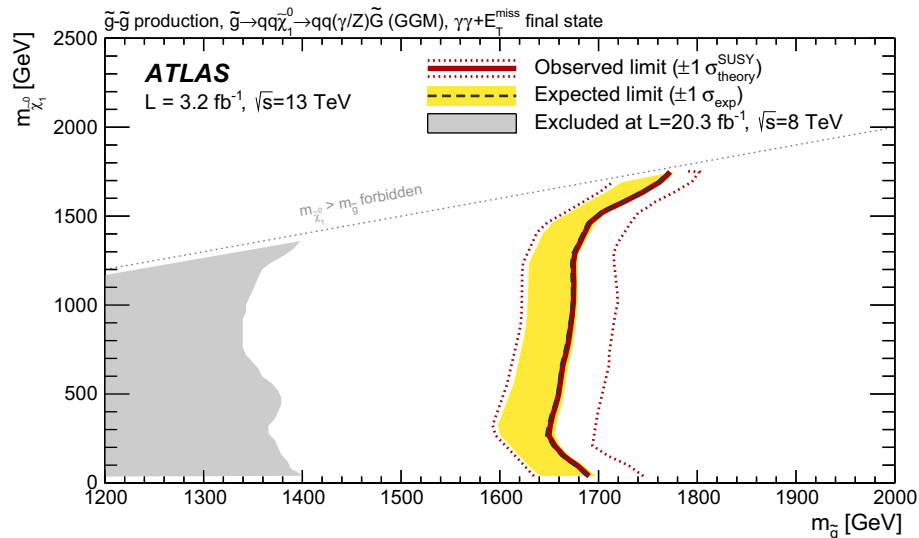


Fig. 3 Exclusion limits in the neutralino–gluino mass plane at 95 % CL. The observed limits are exhibited for the nominal SUSY model cross section, as well as for a SUSY cross section increased and lowered by one standard deviation of the cross-section systematic uncertainty. Also shown is the expected limit, as well as the ± 1 standard-deviation range of the expected limit, which is asymmetric because of the low

count expected. Because the background expectation is close to zero and the observed number of events is zero, the expected and observed limits nearly overlap. The previous limit from ATLAS using 8 TeV data [3] is shown in grey. Within the context of this model, gluino masses as low as 400 GeV have been excluded in a prior analysis making use of 7 TeV ATLAS data [58]

gluino masses as low as 400 GeV have been excluded in a prior analysis making use of 7 TeV ATLAS data [58].

9 Conclusion

A search has been made for a diphoton + E_T^{miss} final state using the ATLAS detector at the Large Hadron Collider in 3.2 fb^{-1} of proton–proton collision data taken at a centre-of-mass energy of 13 TeV in 2015. At least two photon candidates with $p_T > 75 \text{ GeV}$ are required, as well as minimum values of 175 and 1500 GeV of the missing transverse momentum and effective mass of the event, respectively. The resulting signal region targets events with pair-produced high-mass gluinos each decaying to either a high-mass or low-mass bino-like neutralino. Using a combination of data-driven and direct Monte Carlo approaches, the SM background is estimated to be $0.27^{+0.22}_{-0.10}$ events, with most of the expected background arising from the production of a W boson in association with two energetic photons. No events are observed in the signal region; considering the expected background and its uncertainty, this observation implies model-independent 95 % CL upper limits of 3.0 events (0.93 fb) on the number of events (visible cross section) due to physics beyond the Standard Model. In the context of a generalized model of gauge-mediated supersymmetry breaking with a bino-like NLSP, this leads to a lower limit of 1650 GeV on the mass of a degenerate octet of gluino

states, independent of the mass of the lighter bino-like neutralino. This extends the corresponding limit of 1340 GeV derived from a similar analysis of 8 TeV data by the ATLAS Collaboration.

Acknowledgments We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, The Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d’Avenir Labex and Idex, ANR, Région Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF, Norway; Generalitat de Catalunya, Generalitat Valenciana, Spain; the Royal Society and Leverhulme Trust, UK.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [59].

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. Funded by SCOAP³.

References

1. C. Cheung, A.L. Fitzpatrick, D. Shih (Extra)ordinary gauge mediation, *JHEP* **07**, 054 (2008). doi:[10.1088/1126-6708/2008/07/054](https://doi.org/10.1088/1126-6708/2008/07/054). arXiv:[hep-ph/0710.3585](https://arxiv.org/abs/hep-ph/0710.3585) [hep-ph]
2. P. Meade, N. Seiberg, D. Shih, General gauge mediation. *Prog. Theor. Phys. Suppl.* **177**, 143–158 (2009). doi:[10.1143/PTPS.177.143](https://doi.org/10.1143/PTPS.177.143). arXiv:[hep-ph/0801.3278](https://arxiv.org/abs/hep-ph/0801.3278) [hep-ph]
3. ATLAS Collaboration, Search for photonic signatures of gauge-mediated supersymmetry in 8 TeV pp collisions with the ATLAS detector. *Phys. Rev. D* **92**, 072001 (2015). doi:[10.1103/PhysRevD.92.072001](https://doi.org/10.1103/PhysRevD.92.072001). arXiv:[1507.05493](https://arxiv.org/abs/1507.05493) [hep-ex]
4. CMS Collaboration, Search for supersymmetry with photons in pp collisions at $\sqrt{s} = 8$ TeV. *Phys. Rev. D* **92**, 072006 (2015). doi:[10.1103/PhysRevD.92.072006](https://doi.org/10.1103/PhysRevD.92.072006). arXiv:[1507.02898](https://arxiv.org/abs/1507.02898) [hep-ex]
5. Y.A. Golfand, E.P. Likhtman, Extension of the algebra of poicare group generators and violation of p invariance. *JETP Lett.* **13**, 323–326 (1971)
6. D.V. Volkov, V.P. Akulov, Is the Neutrino a Goldstone Particle? *Phys. Lett. B* **46**, 109–110 (1973). doi:[10.1016/0370-2693\(73\)90490-5](https://doi.org/10.1016/0370-2693(73)90490-5)
7. J. Wess, B. Zumino, Supergauge Transformations in Four-Dimensions. *Nucl. Phys. B* **70**, 39–50 (1974). doi:[10.1016/0550-3213\(74\)90355-1](https://doi.org/10.1016/0550-3213(74)90355-1)
8. J. Wess, B. Zumino, Supergauge Invariant Extension of Quantum Electrodynamics. *Nucl. Phys. B* **78**, 1 (1974). doi:[10.1016/0550-3213\(74\)90112-6](https://doi.org/10.1016/0550-3213(74)90112-6)
9. S. Ferrara, B. Zumino, Supergauge Invariant Yang-Mills Theories. *Nucl. Phys. B* **79**, 413 (1974). doi:[10.1016/0550-3213\(74\)90559-8](https://doi.org/10.1016/0550-3213(74)90559-8)
10. A. Salam, J.A. Strathdee, Supersymmetry and nonabelian gauges. *Phys. Lett. B* **51**, 353–355 (1974). doi:[10.1016/0370-2693\(74\)90226-3](https://doi.org/10.1016/0370-2693(74)90226-3)
11. G.R. Farrar, P. Fayet, Phenomenology of the production, decay, and detection of new hadronic states associated with supersymmetry. *Phys. Lett. B* **76**, 575 (1978). doi:[10.1016/0370-2693\(78\)90858-4](https://doi.org/10.1016/0370-2693(78)90858-4)
12. M. Dine, W. Fischler, A phenomenological model of particle physics based on supersymmetry. *Phys. Lett. B* **110**, 227 (1982). doi:[10.1016/0370-2693\(82\)91241-2](https://doi.org/10.1016/0370-2693(82)91241-2)
13. L. Alvarez-Gaume, M. Claudson, M. Wise, Low-energy supersymmetry. *Nucl. Phys. B* **207**, 96 (1982). doi:[10.1016/0550-3213\(82\)90138-9](https://doi.org/10.1016/0550-3213(82)90138-9)
14. C.R. Nappi, B.A. Ovrut, Supersymmetric Extension of the SU(3) x SU(2) x U(1) Model. *Phys. Lett. B* **113**, 175 (1982). doi:[10.1016/0370-2693\(82\)90418-X](https://doi.org/10.1016/0370-2693(82)90418-X)
15. A. Djouadi, J.-L. Kneur, G. Moultaka, SuSpect: A Fortran code for the supersymmetric and Higgs particle spectrum in the MSSM. *Comput. Phys. Commun.* **176**, 426–455 (2007). doi:[10.1016/j.cpc.2006.11.009](https://doi.org/10.1016/j.cpc.2006.11.009). arXiv:[hep-ph/0211331](https://arxiv.org/abs/hep-ph/0211331) [hep-ph]
16. M. Mühlleitner, A. Djouadi and Y. Mambrini, SDECAY: A Fortran code for the decays of the supersymmetric particles in the MSSM. *Comput. Phys. Commun.* **168**, 46–70 (2005). doi:[10.1016/j.cpc.2005.01.012](https://doi.org/10.1016/j.cpc.2005.01.012). arXiv:[hep-ph/0311167](https://arxiv.org/abs/hep-ph/0311167) [hep-ph]
17. A. Djouadi, M. Mühlleitner, M. Spira, Decays of supersymmetric particles: The Program SUSY-HIT (SUSpect-SdecaY-Hdecay-InTeface). *Acta Phys. Polon. B* **38**, 635 (2007). arXiv:[hep-ph/0609292](https://arxiv.org/abs/hep-ph/0609292) [hep-ph]
18. M. Bahr et al., Herwig++ Physics and Manual. *Eur. Phys. J. C* **58**, 639–707 (2008). doi:[10.1140/epjc/s10052-008-0798-9](https://doi.org/10.1140/epjc/s10052-008-0798-9). arXiv:[hep-ph/0803.0883](https://arxiv.org/abs/hep-ph/0803.0883) [hep-ph]
19. J. Pumplin et al., New Generation of Parton Distributions with Uncertainties from Global QCD Analysis. *JHEP* **07**, 012 (2002). doi:[10.1088/1126-6708/2002/07/012](https://doi.org/10.1088/1126-6708/2002/07/012). arXiv:[hep-ph/0201195v3](https://arxiv.org/abs/hep-ph/0201195v3)
20. W. Beenakker et al., Squark and gluino production at hadron colliders. *Nucl. Phys. B* **492**, 51–103 (1997). doi:[10.1016/S0550-3213\(97\)00084-9](https://doi.org/10.1016/S0550-3213(97)00084-9). arXiv:[hep-ph/9610490](https://arxiv.org/abs/hep-ph/9610490) [hep-ph]
21. A. Kulesza, L. Motyka, Threshold resummation for squark-antisquark and gluino-pair production at the LHC. *Phys. Rev. Lett.* **102**, 111802 (2009). doi:[10.1103/PhysRevLett.102.111802](https://doi.org/10.1103/PhysRevLett.102.111802). arXiv:[hep-ph/0807.2405](https://arxiv.org/abs/hep-ph/0807.2405) [hep-ph]
22. A. Kulesza, L. Motyka, Soft gluon resummation for the production of gluino-gluino and squark-antisquark pairs at the LHC. *Phys. Rev. D* **80**, 095004 (2009). doi:[10.1103/PhysRevD.80.095004](https://doi.org/10.1103/PhysRevD.80.095004). arXiv:[hep-ph/0905.4749](https://arxiv.org/abs/hep-ph/0905.4749) [hep-ph]
23. W. Beenakker et al., Soft-gluon resummation for squark and gluino hadroproduction. *JHEP* **12**, 041 (2009). doi:[10.1088/1126-6708/2009/12/041](https://doi.org/10.1088/1126-6708/2009/12/041). arXiv:[hep-ph/0909.4418](https://arxiv.org/abs/hep-ph/0909.4418) [hep-ph]
24. W. Beenakker et al., Squark and gluino hadroproduction. *Int. J. Mod. Phys. A* **26**, 2637–2664 (2011). doi:[10.1142/S0217751X11053560](https://doi.org/10.1142/S0217751X11053560). arXiv:[hep-ph/1105.1110](https://arxiv.org/abs/hep-ph/1105.1110) [hep-ph]
25. M. Botje et al., The PDF4LHC Working Group Interim Recommendations (2011). arXiv:[hep-ph/1101.0538](https://arxiv.org/abs/hep-ph/1101.0538) [hep-ph]
26. T. Gleisberg et al., Event generation with SHERPA 1.1, *JHEP* **02**, 007 (2009). doi:[10.1088/1126-6708/2009/02/007](https://doi.org/10.1088/1126-6708/2009/02/007). arXiv:[hep-ph/0811.4622](https://arxiv.org/abs/hep-ph/0811.4622) [hep-ph]
27. H.-L. Lai et al., New parton distributions for collider physics. *Phys. Rev. D* **82**, 074024 (2010). doi:[10.1103/PhysRevD.82.074024](https://doi.org/10.1103/PhysRevD.82.074024). arXiv:[hep-ph/1007.2241](https://arxiv.org/abs/hep-ph/1007.2241) [hep-ph]
28. S. Schumann, F. Krauss, A Parton shower algorithm based on Catani-Seymour dipole factorisation. *JHEP* **03**, 038 (2008). doi:[10.1088/1126-6708/2008/03/038](https://doi.org/10.1088/1126-6708/2008/03/038). arXiv:[hep-ph/0709.1027](https://arxiv.org/abs/hep-ph/0709.1027) [hep-ph]
29. S. Hoeche et al., QCD matrix elements and truncated showers. *JHEP* **05**, 053 (2009). doi:[10.1088/1126-6708/2009/05/053](https://doi.org/10.1088/1126-6708/2009/05/053). arXiv:[hep-ph/0903.1219](https://arxiv.org/abs/hep-ph/0903.1219) [hep-ph]
30. J. Alwall et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations. *JHEP* **07**, 079 (2014). doi:[10.1007/JHEP07\(2014\)079](https://doi.org/10.1007/JHEP07(2014)079). arXiv:[1405.0301](https://arxiv.org/abs/1405.0301) [hep-ph]
31. T. Sjöstrand, S. Mrenna, P.Z. Skands, A brief introduction to PYTHIA 8.1. *Comput. Phys. Commun.* **178**, 852–867 (2008). doi:[10.1016/j.cpc.2008.01.036](https://doi.org/10.1016/j.cpc.2008.01.036). arXiv:[hep-ph/0710.3820](https://arxiv.org/abs/hep-ph/0710.3820) [hep-ph]
32. R.D. Ball et al., Parton distributions with LHC data. *Nucl. Phys. B* **867**, 244–289 (2013). doi:[10.1016/j.nuclphysb.2012.10.003](https://doi.org/10.1016/j.nuclphysb.2012.10.003). arXiv:[hep-ph/1207.1303](https://arxiv.org/abs/hep-ph/1207.1303) [hep-ph]
33. R.D. Ball et al., Parton distributions with QED corrections. *Nucl. Phys. B* **877**, 290–320 (2013). doi:[10.1016/j.nuclphysb.2013.10.010](https://doi.org/10.1016/j.nuclphysb.2013.10.010). arXiv:[1308.0598](https://arxiv.org/abs/1308.0598) [hep-ph]
34. ATLAS Collaboration, ‘ATLAS Run 1 Pythia8 tunes’, tech. rep. ATL-PHYS-PUB-2014-021, CERN (2014). <http://cds.cern.ch/record/1966419>
35. ATLAS Collaboration, The ATLAS simulation infrastructure. *Eur. Phys. J. C* **70**, 823–874 (2010). doi:[10.1140/epjc/s10052-010-1429-9](https://doi.org/10.1140/epjc/s10052-010-1429-9). arXiv:[1005.4568](https://arxiv.org/abs/1005.4568) [physics.ins-det]

36. S. Agostinelli et al., GEANT4: a simulation toolkit. Nucl. Instrum. Meth. A **506**, 250–303 (2003). doi:[10.1016/S0168-9002\(03\)01368-8](https://doi.org/10.1016/S0168-9002(03)01368-8)
37. ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST **3**, S08003 (2008). doi:[10.1088/1748-0221/3/08/S08003](https://doi.org/10.1088/1748-0221/3/08/S08003)
38. ATLAS Collaboration, 2015 start-up trigger menu and initial performance assessment of the ATLAS trigger using Run-2 data, ATL-DAQ-PUB-2016-001 (2016). <http://cds.cern.ch/record/2136007>
39. ATLAS Collaboration, Improved electron reconstruction in ATLAS using the Gaussian Sum Filter-based model for bremsstrahlung, ATLAS-CONF-2012-047 (2012). <http://cdsweb.cern.ch/record/1449796>
40. ATLAS Collaboration, Electron reconstruction and identification efficiency measurements with the ATLAS detector using the 2011 LHC proton-proton collision data. Eur. Phys. J. C **74**, 2941 (2014). doi:[10.1140/epjc/s10052-014-2941-0](https://doi.org/10.1140/epjc/s10052-014-2941-0). arXiv:1404.2240 [hep-ex]
41. ATLAS Collaboration, Electron identification measurements in ATLAS using $\sqrt{s} = 13$ TeV data with 50 ns bunch spacing, ATL-PHYS-PUB-2015-041 (2015). <http://cdsweb.cern.ch/record/2048202>
42. ATLAS Collaboration, Measurement of the photon identification efficiencies with the ATLAS detector using LHC Run-1 data (2016). arXiv:1606.01813 [hep-ex]
43. ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13$ TeV. Eur. Phys. J. C **76**, 292 (2016). doi:[10.1140/epjc/s10052-016-4120-y](https://doi.org/10.1140/epjc/s10052-016-4120-y). arXiv:1603.05598 [hep-ex]
44. ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1 (2016). arXiv:1512.06092 [hep-ex]
45. M. Cacciari, G. Salam, G. Soyez, The anti- k_t jet clustering algorithm. JHEP **04**, 063 (2008). doi:[10.1088/1126-6708/2008/04/063](https://doi.org/10.1088/1126-6708/2008/04/063). arXiv:0802.1189 [hep-ph]
46. ATLAS Collaboration, Jet calibration and systematic uncertainties for jets reconstructed in the ATLAS Detector at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-015 (2015). <https://cds.cern.ch/record/2037613>
47. ATLAS Collaboration, Monte Carlo calibration and combination of in-situ measurements of jet energy scale, jet energy resolution and jet mass in ATLAS, ATLAS-CONF-2015-037 (2015). <http://cdsweb.cern.ch/record/2044941>
48. ATLAS Collaboration, Tagging and suppression of pileup jets with the ATLAS detector, ATLAS-CONF-2014-018 (2014). <http://cdsweb.cern.ch/record/1700870>
49. ATLAS Collaboration, Performance of missing transverse momentum reconstruction in ATLAS studied in Proton–Proton Collisions recorded in 2012 at $\sqrt{s} = 8$ TeV, ATLAS-CONF-2013-082 (2013). <http://cdsweb.cern.ch/record/1570993>
50. ATLAS Collaboration, Jet energy measurement with the ATLAS detector in proton–proton collisions at $\sqrt{s} = 7$ TeV. Eur. Phys. J. C **73**, 2304 (2013). doi:[10.1140/epjc/s10052-013-2304-2](https://doi.org/10.1140/epjc/s10052-013-2304-2). arXiv:1112.6426 [hep-ex]
51. ATLAS Collaboration, Selection of jets produced in 13 TeV proton–proton collisions with the ATLAS detector, ATLAS-CONF-2015-029 (2015). <http://cdsweb.cern.ch/record/2037702>
52. G. Bozzi et al., $W\gamma\gamma$ production with leptonic decays at NLO QCD. Phys. Rev. D **83**, 114035 (2011). doi:[10.1103/PhysRevD.83.114035](https://doi.org/10.1103/PhysRevD.83.114035). arXiv:1103.4613 [hep-ph]
53. ATLAS Collaboration, Measurements of $Z\gamma$ and $Z\gamma\gamma$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector. Phys. Rev. D **93**, 112002 (2016). doi:[10.1103/PhysRevD.93.112002](https://doi.org/10.1103/PhysRevD.93.112002). arXiv:1604.05232 [hep-ex]
54. ATLAS Collaboration, Performance of the ATLAS Electron and Photon Trigger in pp Collisions at $\sqrt{s} = 7$ TeV in 2011 ATLAS-CONF-2012-048 (2012). <http://cdsweb.cern.ch/record/1450089>
55. ATLAS Collaboration, Improved luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC. Eur. Phys. J. C **73**, 2518 (2013). doi:[10.1140/epjc/s10052-013-2518-3](https://doi.org/10.1140/epjc/s10052-013-2518-3). arXiv:1302.4393 [hep-ex]
56. ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using LHC Run 1 data. Eur. Phys. J. C **74**, 3071 (2014). doi:[10.1140/epjc/s10052-014-3071-4](https://doi.org/10.1140/epjc/s10052-014-3071-4). arXiv:1407.5063 [hep-ex]
57. A.L. Read, Presentation of search results: The CL_s technique. J. Phys. G **28**, 2693 (2002). doi:[10.1088/0954-3899/28/10/313](https://doi.org/10.1088/0954-3899/28/10/313)
58. ATLAS Collaboration, Search for Diphoton Events with Large Missing Transverse Energy with 36 pb^{-1} of 7 TeV Proton–Proton Collision Data with the ATLAS Detector. Eur. Phys. J. C **71**, 1744 (2011). doi:[10.1140/epjc/s10052-011-1744-9](https://doi.org/10.1140/epjc/s10052-011-1744-9). arXiv:1107.0561 [hep-ex]
59. ATLAS Collaboration, ATLAS Computing Acknowledgements 2016–2017 ATL-GEN-PUB-2016-002 (2016). <http://cds.cern.ch/record/2202407>

ATLAS Collaboration

M. Aaboud^{135d}, G. Aad⁸⁶, B. Abbott¹¹³, J. Abdallah⁶⁴, O. Abdinov¹², B. Abeloos¹¹⁷, R. Aben¹⁰⁷, O. S. AbouZeid¹³⁷, N. L. Abraham¹⁴⁹, H. Abramowicz¹⁵³, H. Abreu¹⁵², R. Abreu¹¹⁶, Y. Abulaiti^{146a,146b}, B. S. Acharya^{163a,163b,a}, S. Adachi¹⁵⁵, L. Adamczyk^{40a}, D. L. Adams²⁷, J. Adelman¹⁰⁸, S. Adomeit¹⁰⁰, T. Adye¹³¹, A. A. Affolder⁷⁵, T. Agatonovic-Jovin¹⁴, J. Agricola⁵⁶, J. A. Aguilar-Saavedra^{126a,126f}, S. P. Ahlen²⁴, F. Ahmadov^{66,b}, G. Aielli^{133a,133b}, H. Akerstedt^{146a,146b}, T. P. A. Åkesson⁸², A. V. Akimov⁹⁶, G. L. Alberghi^{22a,22b}, J. Albert¹⁶⁸, S. Albrand⁵⁷, M. J. Alconada Verzini⁷², M. Aleksa³², I. N. Aleksandrov⁶⁶, C. Alexa^{28b}, G. Alexander¹⁵³, T. Alexopoulos¹⁰, M. Alhroob¹¹³, B. Ali¹²⁸, M. Aliev^{74a,74b}, G. Alimonti^{92a}, J. Alison³³, S. P. Alkire³⁷, B. M. M. Allbrooke¹⁴⁹, B. W. Allen¹¹⁶, P. P. Allport¹⁹, A. Aloisio^{104a,104b}, A. Alonso³⁸, F. Alonso⁷², C. Alpigiani¹³⁸, A. A. Alshehri⁵⁵, M. Alstady⁸⁶, B. Alvarez Gonzalez³², D. Álvarez Piqueras¹⁶⁶, M. G. Alviggi^{104a,104b}, B. T. Amadio¹⁶, K. Amako⁶⁷, Y. Amaral Coutinho^{26a}, C. Amelung²⁵, D. Amidei⁹⁰, S. P. Amor Dos Santos^{126a,126c}, A. Amorim^{126a,126b}, S. Amoroso³², G. Amundsen²⁵, C. Anastopoulos¹³⁹, L. S. Ancu⁵¹, N. Andari¹⁹, T. Andeen¹¹, C. F. Anders^{59b}, G. Anders³², J. K. Anders⁷⁵, K. J. Anderson³³, A. Andreazza^{92a,92b}, V. Andrei^{59a}, S. Angelidakis⁹, I. Angelozzi¹⁰⁷, P. Anger⁴⁶, A. Angerami³⁷, F. Anghinolfi³², A. V. Anisenkov^{109,c}, N. Anjos¹³, A. Annovi^{124a,124b}, C. Antel^{59a}, M. Antonelli⁴⁹, A. Antonov^{98,*}, F. Anulli^{132a}, M. Aoki⁶⁷, L. Aperio Bella¹⁹, G. Arabidze⁹¹, Y. Arai⁶⁷, J. P. Araque^{126a}, A. T. H. Arce⁴⁷, F. A. Arduh⁷², J.-F. Arguin⁹⁵, S. Argyropoulos⁶⁴, M. Arik^{20a}, A. J. Armbruster¹⁴³, L. J. Armitage⁷⁷, O. Arnaez³², H. Arnold⁵⁰, M. Arratia³⁰, O. Arslan²³, A. Artamonov⁹⁷, G. Artoni¹²⁰, S. Artz⁸⁴, S. Asai¹⁵⁵, N. Asbah⁴⁴, A. Ashkenazi¹⁵³, B. Åsman^{146a,146b}, L. Asquith¹⁴⁹, K. Assamagan²⁷, R. Astalos^{144a}, M. Atkinson¹⁶⁵, N. B. Atlay¹⁴¹, K. Augsten¹²⁸, G. Avolio³², B. Axen¹⁶, M. K. Ayoub¹¹⁷, G. Azuelos^{95,d}, M. A. Baak³², A. E. Baas^{59a}, M. J. Baca¹⁹, H. Bachacou¹³⁶, K. Bachas^{74a,74b}, M. Backes¹²⁰, M. Backhaus³², P. Bagiacchi^{132a,132b}, P. Bagnaia^{132a,132b}, Y. Bai^{35a}, J. T. Baines¹³¹, O. K. Baker¹⁷⁵, E. M. Baldwin^{109,c}, P. Balek¹⁷¹, T. Balestri¹⁴⁸, F. Balli¹³⁶, W. K. Balunas¹²², E. Banas⁴¹, Sw. Banerjee^{172,e}, A. A. E. Bannoura¹⁷⁴, L. Barak³², E. L. Barberio⁸⁹, D. Barberis^{52a,52b}, M. Barbero⁸⁶, T. Barillari¹⁰¹, M.-S. Barisits³², T. Barklow¹⁴³, N. Barlow³⁰, S. L. Barnes⁸⁵, B. M. Barnett¹³¹, R. M. Barnett¹⁶, Z. Barnovska-Blenessy⁵, A. Baroncelli^{134a}, G. Barone²⁵, A. J. Barr¹²⁰, L. Barranco Navarro¹⁶⁶, F. Barreiro⁸³, J. Barreiro Guimarães da Costa^{35a}, R. Bartoldus¹⁴³, A. E. Barton⁷³, P. Bartos^{144a}, A. Basalae¹²³, A. Bassalat¹¹⁷, R. L. Bates⁵⁵, S. J. Batista¹⁵⁸, J. R. Batley³⁰, M. Battaglia¹³⁷, M. Baue^{132a,132b}, F. Bauer¹³⁶, H. S. Bawa^{143,f}, J. B. Beacham¹¹¹, M. D. Beattie⁷³, T. Beau⁸¹, P. H. Beauchemin¹⁶¹, P. Bechtel²³, H. P. Beck^{18,g}, K. Becker¹²⁰, M. Becker⁸⁴, M. Beckingham¹⁶⁹, C. Becot¹¹⁰, A. J. Beddall^{20d}, A. Beddall^{20b}, V. A. Bednyakov⁶⁶, M. Bedognetti¹⁰⁷, C. P. Bee¹⁴⁸, L. J. Beemster¹⁰⁷, T. A. Beermann³², M. Begel²⁷, J. K. Behr⁴⁴, C. Belanger-Champagne⁸⁸, A. S. Bell⁷⁹, G. Bella¹⁵³, L. Bellagamba^{22a}, A. Bellerive³¹, M. Bellomo⁸⁷, K. Belotskiy⁹⁸, O. Beltramello³², N. L. Belyaev⁹⁸, O. Benary¹⁵³, D. Benchekroun^{135a}, M. Bender¹⁰⁰, K. Bendtz^{146a,146b}, N. Benekos¹⁰, Y. Benhammou¹⁵³, E. Benhar Nocchioli¹⁷⁵, J. Benitez⁶⁴, D. P. Benjamin⁴⁷, J. R. Bensinger²⁵, S. Bentvelsen¹⁰⁷, L. Beresford¹²⁰, M. Beretta⁴⁹, D. Berge¹⁰⁷, E. Bergeas Kuutmann¹⁶⁴, N. Berger⁵, J. Beringer¹⁶, S. Berlendis⁵⁷, N. R. Bernard⁸⁷, C. Bernius¹¹⁰, F. U. Bernlochner²³, T. Berry⁷⁸, P. Berta¹²⁹, C. Bertella⁸⁴, G. Bertoli^{146a,146b}, F. Bertolucci^{124a,124b}, I. A. Bertram⁷³, C. Bertsche⁴⁴, D. Bertsche¹¹³, G. J. Besjes³⁸, O. Bessidskaia Bylund^{146a,146b}, M. Bessner⁴⁴, N. Besson¹³⁶, C. Betancourt⁵⁰, A. Bethani⁵⁷, S. Bethke¹⁰¹, A. J. Bevan⁷⁷, R. M. Bianchi¹²⁵, L. Bianchini²⁵, M. Bianco³², O. Biebel¹⁰⁰, D. Biedermann¹⁷, R. Bielski⁸⁵, N. V. Biesuz^{124a,124b}, M. Biglietti^{134a}, J. Bilbao De Mendizabal⁵¹, T. R. V. Billoud⁹⁵, H. Bilokon⁴⁹, M. Bindi⁵⁶, S. Binet¹¹⁷, A. Bingul^{20b}, C. Bini^{132a,132b}, S. Biondi^{22a,22b}, T. Bisanz⁵⁶, D. M. Bjergaard⁴⁷, C. W. Black¹⁵⁰, J. E. Black¹⁴³, K. M. Black²⁴, D. Blackburn¹³⁸, R. E. Blair⁶, J. -B. Blanchard¹³⁶, T. Blazek^{144a}, I. Bloch⁴⁴, C. Blocker²⁵, A. Blue⁵⁵, W. Blum^{84,*}, U. Blumenschein⁵⁶, S. Blunier^{34a}, G. J. Bobbink¹⁰⁷, V. S. Bobrovnikov^{109,c}, S. S. Bocchetta⁸², A. Bocci⁴⁷, C. Bock¹⁰⁰, M. Boehler⁵⁰, D. Boerner¹⁷⁴, J. A. Bogaerts³², D. Bogavac¹⁴, A. G. Bogdanchikov¹⁰⁹, C. Bohm^{146a}, V. Boisvert⁷⁸, P. Bokan¹⁴, T. Bold^{40a}, A. S. Boldyrev^{163a,163c}, M. Bomben⁸¹, M. Bona⁷⁷, M. Boonekamp¹³⁶, A. Borisov¹³⁰, G. Borissov⁷³, J. Bortfeldt³², D. Bortoletto¹²⁰, V. Bortolotto^{61a,61b,61c}, K. Bos¹⁰⁷, D. Boscherini^{22a}, M. Bosman¹³, J. D. Bossio Sola²⁹, J. Boudreau¹²⁵, J. Bouffard², E. V. Bouhova-Thacker⁷³, D. Boumediene³⁶, C. Bourdarios¹¹⁷, S. K. Boutle⁵⁵, A. Boveia³², J. Boyd³², I. R. Boyko⁶⁶, J. Bracinik¹⁹, A. Brandt⁸, G. Brandt⁵⁶, O. Brandt^{59a}, U. Bratzler¹⁵⁶, B. Brau⁸⁷, J. E. Brau¹¹⁶, H. M. Braun^{174,*}, W. D. Breaden Madden⁵⁵, K. Brendlinger¹²², A. J. Brennan⁸⁹, L. Brenner¹⁰⁷, R. Brenner¹⁶⁴, S. Bressler¹⁷¹, T. M. Bristow⁴⁸, D. Britton⁵⁵, D. Britzger⁴⁴, F. M. Brochu³⁰, I. Brock²³, R. Brock⁹¹, G. Brooijmans³⁷, T. Brooks⁷⁸, W. K. Brooks^{34b}, J. Brosamer¹⁶, E. Brost¹⁰⁸, J. H. Broughton¹⁹, P. A. Bruckman de Renstrom⁴¹, D. Bruncko^{144b}, R. Bruneliere⁵⁰, A. Bruni^{22a}, G. Bruni¹⁴², L. S. Bruni¹⁰⁷, B. H. Brunt³⁰, M. Bruschi^{22a}, N. Bruscino²³, P. Bryant³³, L. Bryngemark⁸², T. Buane¹⁵, Q. Buat¹²², P. Buchholz¹⁴¹, A. G. Buckley⁵⁵, I. A. Budagov⁶⁶, F. Buehrer⁵⁰, M. K. Bugge¹¹⁹, O. Bulekov⁹⁸, D. Bullock⁸, H. Burckhart³², S. Burdin⁷⁵, C. D. Burgard⁵⁰, B. Burghgrave¹⁰⁸, K. Burka⁴¹, S. Burke¹³¹, I. Burmeister⁴⁵, J. T. P. Burr¹²⁰, E. Busato³⁶, D. Büscher⁵⁰, V. Büscher⁸⁴, P. Bussey⁵⁵, J. M. Butler²⁴, C. M. Buttar⁵⁵, J. M. Butterworth⁷⁹, P. Butti¹⁰⁷, W. Buttinger²⁷,

- A. Buzatu⁵⁵, A. R. Buzykaev^{109,c}, S. Cabrera Urbán¹⁶⁶, D. Caforio¹²⁸, V. M. Cairo^{39a,39b}, O. Cakir^{4a}, N. Calace⁵¹, P. Calafiura¹⁶, A. Calandri⁸⁶, G. Calderini⁸¹, P. Calfayan¹⁰⁰, G. Callea^{39a,39b}, L. P. Caloba^{26a}, S. Calvente Lopez⁸³, D. Calvet³⁶, S. Calvet³⁶, T. P. Calvet⁸⁶, R. Camacho Toro³³, S. Camarda³², P. Camarri^{133a,133b}, D. Cameron¹¹⁹, R. Caminal Armadans¹⁶⁵, C. Camincher⁵⁷, S. Campana³², M. Campanelli⁷⁹, A. Camplani^{92a,92b}, A. Campoverde¹⁴¹, V. Canale^{104a,104b}, A. Canepa^{159a}, M. Cano Bret^{35e}, J. Cantero¹¹⁴, T. Cao⁴², M. D. M. Capeans Garrido³², I. Caprini^{28b}, M. Caprini^{28b}, M. Capua^{39a,39b}, R. M. Carbone³⁷, R. Cardarelli^{133a}, F. Cardillo⁵⁰, I. Carli¹²⁹, T. Carli³², G. Carlino^{104a}, L. Carminati^{92a,92b}, S. Caron¹⁰⁶, E. Carquin^{34b}, G. D. Carrillo-Montoya³², J. R. Carter³⁰, J. Carvalho^{126a,126c}, D. Casadei¹⁹, M. P. Casado^{13,h}, M. Casolino¹³, D. W. Casper¹⁶², E. Castaneda-Miranda^{145a}, R. Castelijns¹⁰⁷, A. Castelli¹⁰⁷, V. Castillo Gimenez¹⁶⁶, N. F. Castro^{126a,i}, A. Catinaccio³², J. R. Catmore¹¹⁹, A. Cattai³², J. Caudron²³, V. Cavaliere¹⁶⁵, E. Cavallaro¹³, D. Cavalli^{92a}, M. Cavalli-Sforza¹³, V. Cavasinni^{124a,124b}, F. Ceradini^{134a,134b}, L. Cerda Alberich¹⁶⁶, B. C. Cerio⁴⁷, A. S. Cerqueira^{26b}, A. Cerri¹⁴⁹, L. Cerrito^{133a,133b}, F. Cerutti¹⁶, M. Cerv³², A. Cervelli¹⁸, S. A. Cetin^{20c}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁸, S. K. Chan⁵⁸, Y. L. Chan^{61a}, P. Chang¹⁶⁵, J. D. Chapman³⁰, D. G. Charlton¹⁹, A. Chatterjee⁵¹, C. C. Chau¹⁵⁸, C. A. Chavez Barajas¹⁴⁹, S. Che¹¹¹, S. Cheatham^{163a,163c}, A. Chegwidan⁹¹, S. Chekanov⁶, S. V. Chekulaev^{159a}, G. A. Chelkov^{66,j}, M. A. Chelstowska⁹⁰, C. Chen⁶⁵, H. Chen²⁷, K. Chen¹⁴⁸, S. Chen^{35c}, S. Chen¹⁵⁵, X. Chen^{35f}, Y. Chen⁶⁸, H. C. Cheng⁹⁰, H. J. Cheng^{35a}, Y. Cheng³³, A. Cheplakov⁶⁶, E. Cheremushkina¹³⁰, R. Cherkaoui El Moursli^{135e}, V. Chernyatin^{27,*}, E. Cheu⁷, L. Chevalier¹³⁶, V. Chiarella⁴⁹, G. Chiarelli^{124a,124b}, G. Chiodini^{74a}, A. S. Chisholm³², A. Chitan^{28b}, M. V. Chizhov⁶⁶, K. Choi⁶², A. R. Chomont³⁶, S. Chouridou⁹, B. K. B. Chow¹⁰⁰, V. Christodoulou⁷⁹, D. Chromek-Burckhart³², J. Chudoba¹²⁷, A. J. Chuinard⁸⁸, J. J. Chwastowski⁴¹, L. Chytka¹¹⁵, G. Ciapetti^{132a,132b}, A. K. Ciftci^{4a}, D. Cinca⁴⁵, V. Cindro⁷⁶, I. A. Cioara²³, C. Ciocca^{22a,22b}, A. Ciochio¹⁶, F. Ciotto^{104a,104b}, Z. H. Citron¹⁷¹, M. Citterio^{92a}, M. Ciubancan^{28b}, A. Clark⁵¹, B. L. Clark⁵⁸, M. R. Clark³⁷, P. J. Clark¹⁰⁶, R. N. Clarke¹⁶, C. Clement^{146a,146b}, Y. Coadou⁸⁶, M. Cobal^{163a,163c}, A. Coccaro⁵¹, J. Cochran⁶⁵, L. Colasurdo¹⁰⁶, B. Cole³⁷, A. P. Colijn¹⁰⁷, J. Collot⁵⁷, T. Colombo¹⁶², G. Compostella¹⁰¹, P. Conde Muñio^{126a,126b}, E. Coniavitis⁵⁰, S. H. Connell^{145b}, I. A. Connolly⁷⁸, V. Consorti⁵⁰, S. Constantinescu^{28b}, G. Conti³², F. Conventi^{104a,k}, M. Cooke¹⁶, B. D. Cooper⁷⁹, A. M. Cooper-Sarkar¹²⁰, K. J. R. Cormier¹⁵⁸, T. Cornelissen¹⁷⁴, M. Corradi^{132a,132b}, F. Corriveau^{88,l}, A. Corso-Radu¹⁶², A. Cortes-Gonzalez³², G. Cortiana¹⁰¹, G. Costa^{92a}, M. J. Costa¹⁶⁶, D. Costanzo¹³⁹, G. Cottin³⁰, G. Cowan⁷⁸, B. E. Cox⁸⁵, K. Cranmer¹¹⁰, S. J. Crawley⁵⁵, G. Cree³¹, S. Crépe-Renaudin⁵⁷, F. Crescioli⁸¹, W. A. Cribbs^{146a,146b}, M. Crispin Ortuzar¹²⁰, M. Cristinziani²³, V. Croft¹⁰⁶, G. Crosetti^{39a,39b}, A. Cueto⁸³, T. Cuhadar Donszelmann¹³⁹, J. Cummings¹⁷⁵, M. Curatolo⁴⁹, J. Cúth⁸⁴, H. Czirr¹⁴¹, P. Czodrowski³, G. D'amen^{22a,22b}, S. D'Auria⁵⁵, M. D'Onofrio⁷⁵, M. J. Da Cunha Sargedass De Sousa^{126a,126b}, C. Da Via⁸⁵, W. Dabrowski^{40a}, T. Dado^{144a}, T. Dai⁹⁰, O. Dale¹⁵, F. Dallaire⁹⁵, C. Dallapiccola⁸⁷, M. Dam³⁸, J. R. Dandoy³³, N. P. Dang⁵⁰, A. C. Daniells¹⁹, N. S. Dann⁸⁵, M. Danninger¹⁶⁷, M. Dano Hoffmann¹³⁶, V. Dao⁵⁰, G. Darbo^{52a}, S. Darmora⁸, J. Dassoulas³, A. Dattagupta¹¹⁶, W. Davey²³, C. David¹⁶⁸, T. Davidek¹²⁹, M. Davies¹⁵³, P. Davison⁷⁹, E. Dawe⁸⁹, I. Dawson¹³⁹, K. De⁸, R. de Asmundis^{104a}, A. De Benedetti¹¹³, S. De Castro^{22a,22b}, S. De Cecco⁸¹, N. De Groot¹⁰⁶, P. de Jong¹⁰⁷, H. De la Torre⁹¹, F. De Lorenzi⁶⁵, A. De Maria⁵⁶, D. De Pedis^{132a}, A. De Salvo^{132a}, U. De Sanctis¹⁴⁹, A. De Santo¹⁴⁹, J. B. De Vivie De Regie¹¹⁷, W. J. Dearnaley⁷³, R. Debbé²⁷, C. Debenedetti¹³⁷, D. V. Dedovich⁶⁶, N. Dehghanian³, I. Deigaard¹⁰⁷, M. Del Gaudio^{39a,39b}, J. Del Peso⁸³, T. Del Prete^{124a,124b}, D. Delgove¹¹⁷, F. Deliot¹³⁶, C. M. Delitzsch⁵¹, A. Dell'Acqua³², L. Dell'Asta²⁴, M. Dell'Orso^{124a,124b}, M. Della Pietra^{104a,k}, D. della Volpe⁵¹, M. Delmastro⁵, P. A. Delsart⁵⁷, D. A. DeMarco¹⁵⁸, S. Demers¹⁷⁵, M. Demichev⁶⁶, A. Demilly⁸¹, S. P. Denisov¹³⁰, D. Denysiuk¹³⁶, D. Derendarz⁴¹, J. E. Derkaoui^{135d}, F. Derue⁸¹, P. Dervan⁷⁵, K. Desch²³, C. Deterre⁴⁴, K. Dette⁴⁵, P. O. Deviveiros³², A. Dewhurst¹³¹, S. Dhaliwal²⁵, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁵, W. K. Di Clemente¹²², C. Di Donato^{132a,132b}, A. Di Girolamo³², B. Di Girolamo³², B. Di Micco^{134a,134b}, R. Di Nardo³², A. Di Simone⁵⁰, R. Di Sipio¹⁵⁸, D. Di Valentino³¹, C. Diaconu⁸⁶, M. Diamond¹⁵⁸, F. A. Dias⁴⁸, M. A. Diaz^{34a}, E. B. Diehl⁹⁰, J. Dietrich¹⁷, S. Díez Cornell⁴⁴, A. Dimitrievska¹⁴, J. Dingfelder²³, P. Dita^{28b}, S. Dita^{28b}, F. Dittus³², F. Djama⁸⁶, T. Djobava^{53b}, J. I. Djuvsland^{59a}, M. A. B. do Vale^{26c}, D. Dobos³², M. Dobre^{28b}, C. Doglioni⁸², J. Dolejsi¹²⁹, Z. Dolezal¹²⁹, M. Donadelli^{26d}, S. Donati^{124a,124b}, P. Dondero^{121a,121b}, J. Donini³⁶, J. Dopke¹³¹, A. Doria^{104a}, M. T. Dova⁷², A. T. Doyle⁵⁵, E. Drechsler⁵⁶, M. Dris¹⁰, Y. Du^{35d}, J. Duarte-Camperderos¹⁵³, E. Duchovni¹⁷¹, G. Duckeck¹⁰⁰, O. A. Ducu^{95,m}, D. Duda¹⁰⁷, A. Dudarev³², A. Chr. Dudder⁸⁴, E. M. Duffield¹⁶, L. Duflot¹¹⁷, M. Dührssen³², M. Dumancic¹⁷¹, M. Dunford^{59a}, H. Duran Yildiz^{4a}, M. Düren⁵⁴, A. Durglishvili^{53b}, D. Duschinger⁴⁶, B. Dutta⁴⁴, M. Dyndal⁴⁴, C. Eckardt⁴⁴, K. M. Ecker¹⁰¹, R. C. Edgar⁹⁰, N. C. Edwards⁴⁸, T. Eifert³², G. Eigen¹⁵, K. Einsweiler¹⁶, T. Ekelof¹⁶⁴, M. El Kacimi^{135c}, V. Ellajosyula⁸⁶, M. Ellert¹⁶⁴, S. Elles⁵, F. Ellinghaus¹⁷⁴, A. A. Elliot¹⁶⁸, N. Ellis³², J. Elmsheuser²⁷, M. Elsing³², D. Emeliyanov¹³¹, Y. Enari¹⁵⁵, O. C. Endner⁸⁴, J. S. Ennis¹⁶⁹, J. Erdmann⁴⁵, A. Ereditato¹⁸, G. Ernis¹⁷⁴, J. Ernst², M. Ernst²⁷, S. Errede¹⁶⁵, E. Ertel⁸⁴, M. Escalier¹¹⁷, H. Esch⁴⁵, C. Escobar¹²⁵, B. Esposito⁴⁹, A. I. Etiennevire¹³⁶, E. Etzion¹⁵³, H. Evans⁶², A. Ezhilov¹²³, M. Ezzi^{135e}, F. Fabbri^{22a,22b}, L. Fabbri^{22a,22b}

- G. Facini³³, R. M. Fakhruddinov¹³⁰, S. Falciano^{132a}, R. J. Falla⁷⁹, J. Faltova³², Y. Fang^{35a}, M. Fanti^{92a,92b}, A. Farbin⁸, A. Farilla^{134a}, C. Farina¹²⁵, E. M. Farina^{121a,121b}, T. Farooque¹³, S. Farrell¹⁶, S. M. Farrington¹⁶⁹, P. Farthouat³², F. Fassi^{135e}, P. Fassnacht³², D. Fassouliotis⁹, M. Faucci Giannelli⁷⁸, A. Favareto^{52a,52b}, W. J. Fawcett¹²⁰, L. Fayard¹¹⁷, O. L. Fedin^{123,n}, W. Fedorko¹⁶⁷, S. Feigl¹¹⁹, L. Feligioni⁸⁶, C. Feng^{35d}, E. J. Feng³², H. Feng⁹⁰, A. B. Fenyuk¹³⁰, L. Feremenga⁸, P. Fernandez Martinez¹⁶⁶, S. Fernandez Perez¹³, J. Ferrando⁴⁴, A. Ferrari¹⁶⁴, P. Ferrari¹⁰⁷, R. Ferrari^{121a}, D. E. Ferreira de Lima^{59b}, A. Ferrer¹⁶⁶, D. Ferrere⁵¹, C. Ferretti⁹⁰, A. Ferretto Parodi^{52a,52b}, F. Fiedler⁸⁴, A. Filipčić⁷⁶, M. Filipuzzi⁴⁴, F. Filthaut¹⁰⁶, M. Fincke-Keeler¹⁶⁸, K. D. Finelli¹⁵⁰, M. C. N. Fiolhais^{126a,126c}, L. Fiorini¹⁶⁶, A. Firan⁴², A. Fischer², C. Fischer¹³, J. Fischer¹⁷⁴, W. C. Fisher⁹¹, N. Flaschel⁴⁴, I. Fleck¹⁴¹, P. Fleischmann⁹⁰, G. T. Fletcher¹³⁹, R. R. M. Fletcher¹²², T. Flick¹⁷⁴, L. R. Flores Castillo^{61a}, M. J. Flowerdew¹⁰¹, G. T. Forcolin⁸⁵, A. Formica¹³⁶, A. Forti⁸⁵, A. G. Foster¹⁹, D. Fournier¹¹⁷, H. Fox⁷³, S. Fracchia¹³, P. Francavilla⁸¹, M. Franchini^{22a,22b}, D. Francis³², L. Franconi¹¹⁹, M. Franklin⁵⁸, M. Frate¹⁶², M. Fraternali^{121a,121b}, D. Freeborn⁷⁹, S. M. Fressard-Batraneanu³², F. Friedrich⁴⁶, D. Froidevaux³², J. A. Frost¹²⁰, C. Fukunaga¹⁵⁶, E. Fullana Torregrosa⁸⁴, T. Fusayasu¹⁰², J. Fuster¹⁶⁶, C. Gabaldon⁵⁷, O. Gabizon¹⁷⁴, A. Gabrielli^{22a,22b}, A. Gabrielli¹⁶, G. P. Gach^{40a}, S. Gadatsch³², S. Gadomski⁷⁸, G. Gagliardi^{52a,52b}, L. G. Gagnon⁹⁵, P. Gagnon⁶², C. Galea¹⁰⁶, B. Galhardo^{126a,126c}, E. J. Gallas¹²⁰, B. J. Gallop¹³¹, P. Gallus¹²⁸, G. Galster³⁸, K. K. Gan¹¹¹, J. Gao^{35b}, Y. Gao⁴⁸, Y. S. Gao^{143,f}, F. M. Garay Walls⁴⁸, C. García¹⁶⁶, J. E. García Navarro¹⁶⁶, M. Garcia-Sciveres¹⁶, R. W. Gardner³³, N. Garelli¹⁴³, V. Garonne¹¹⁹, A. Gascon Bravo⁴⁴, K. Gasnikova⁴⁴, C. Gatti⁴⁹, A. Gaudiello^{52a,52b}, G. Gaudio^{121a}, L. Gauthier⁹⁵, I. L. Gavrilenko⁹⁶, C. Gay¹⁶⁷, G. Gaycken²³, E. N. Gazis¹⁰, Z. Gece¹⁶⁷, C. N. P. Gee¹³¹, Ch. Geich-Gimbel²³, M. Geisen⁸⁴, M. P. Geisler^{59a}, K. Gellerstedt^{146a,146b}, C. Gemme^{52a}, M. H. Genest⁵⁷, C. Geng^{35b,o}, S. Gentile^{132a,132b}, C. Gentsos¹⁵⁴, S. George⁷⁸, D. Gerbaudo¹³, A. Gershon¹⁵³, S. Ghasemi¹⁴¹, M. Ghneimat²³, B. Giacobbe^{22a}, S. Giagu^{132a,132b}, P. Giannetti^{124a,124b}, B. Gibbard²⁷, S. M. Gibson⁷⁸, M. Gignac¹⁶⁷, M. Gilchriese¹⁶, T. P. S. Gillam³⁰, D. Gillberg³¹, G. Gilles¹⁷⁴, D. M. Gingrich^{3,d}, N. Giokaris⁹, M. P. Giordani^{163a,163c}, F. M. Giorgi^{22a}, F. M. Giorgi¹⁷, P. F. Giraud¹³⁶, P. Giromini⁵⁸, D. Giugni^{92a}, F. Giulì¹²⁰, C. Giuliani¹⁰¹, M. Giulini^{59b}, B. K. Gjelsten¹¹⁹, S. Gkaitatzis¹⁵⁴, I. Gkialas¹⁵⁴, E. L. Gkougkousis¹¹⁷, L. K. Gladilin⁹⁹, C. Glasman⁸³, J. Glatzer⁵⁰, P. C. F. Glaysher⁴⁸, A. Glazov⁴⁴, M. Goblirsch-Kolb²⁵, J. Godlewski⁴¹, S. Goldfarb⁸⁹, T. Golling⁵¹, D. Golubkov¹³⁰, A. Gomes^{126a,126b,126d}, R. Gonçalves^{126a}, J. Goncalves Pinto Firmino Da Costa¹³⁶, G. Gonella⁵⁰, L. Gonella¹⁹, A. Gongadze⁶⁶, S. González de la Hoz¹⁶⁶, G. Gonzalez Parra¹³, S. Gonzalez-Sevilla⁵¹, L. Goossens³², P. A. Gorbounov⁹⁷, H. A. Gordon²⁷, I. Gorelov¹⁰⁵, B. Gorini³², E. Gorini^{74a,74b}, A. Gorišek⁷⁶, E. Gornicki⁴¹, A. T. Goshaw⁴⁷, C. Gössling⁴⁵, M. I. Gostkin⁶⁶, C. R. Goudet¹¹⁷, D. Goujdami^{135c}, A. G. Goussiou¹³⁸, N. Govender^{145b,p}, E. Gozani¹⁵², L. Graber⁵⁶, I. Grabowska-Bold^{40a}, P. O. J. Gradin⁵⁷, P. Grafström^{22a,22b}, J. Gramling⁵¹, E. Gramstad¹¹⁹, S. Grancagnolo¹⁷, V. Gratchev¹²³, P. M. Gravila^{28e}, H. M. Gray³², E. Graziani^{134a}, Z. D. Greenwood^{80,q}, C. Greife²³, K. Gregersen⁷⁹, I. M. Gregor⁴⁴, P. Grenier¹⁴³, K. Grevtsov⁵, J. Griffiths⁸, A. A. Grillo¹³⁷, K. Grimm⁷³, S. Grinstein^{13,r}, Ph. Gris³⁶, J. -F. Grivaz¹¹⁷, S. Groh⁸⁴, J. P. Grohs⁴⁶, E. Gross¹⁷¹, J. Grosse-Knetter⁵⁶, G. C. Grossi⁸⁰, Z. J. Grout⁷⁹, L. Guan⁹⁰, W. Guan¹⁷², J. Guenther⁶³, F. Guescini⁵¹, D. Guest¹⁶², O. Gueta¹⁵³, E. Guido^{52a,52b}, T. Guillemin⁵, S. Guindon², U. Gul⁵⁵, C. Gumpert³², J. Guo^{35e}, Y. Guo^{35b,o}, R. Gupta⁴², S. Gupta¹²⁰, G. Gustavino^{132a,132b}, P. Gutierrez¹¹³, N. G. Gutierrez Ortiz⁷⁹, C. Gutsche⁴⁶, C. Guyot¹³⁶, C. Gwenlan¹²⁰, C. B. Gwilliam⁷⁵, A. Haas¹¹⁰, C. Haber¹⁶, H. K. Hadavand⁸, N. Haddad^{135e}, A. Hader⁸⁶, S. Hageböck²³, M. Hagihara¹⁶⁰, Z. Hajduk⁴¹, H. Hakobyan^{176,*}, M. Haleem⁴⁴, J. Haley¹¹⁴, G. Halladjian⁹¹, G. D. Hallewell⁸⁶, K. Hamacher¹⁷⁴, P. Hamal¹¹⁵, K. Hamano¹⁶⁸, A. Hamilton^{145a}, G. N. Hamity¹³⁹, P. G. Hamnett⁴⁴, L. Han^{35b}, K. Hanagaki^{67,s}, K. Hanawa¹⁵⁵, M. Hance¹³⁷, B. Haney¹²², P. Hanke^{59a}, R. Hanna¹³⁶, J. B. Hansen³⁸, J. D. Hansen³⁸, M. C. Hansen²³, P. H. Hansen³⁸, K. Hara¹⁶⁰, A. S. Hard¹⁷², T. Harenberg¹⁷⁴, F. Hariri¹¹⁷, S. Harkusha⁹³, R. D. Harrington⁴⁸, P. F. Harrison¹⁶⁹, F. Hartjes¹⁰⁷, N. M. Hartmann¹⁰⁰, M. Hasegawa⁶⁸, Y. Hasegawa¹⁴⁰, A. Hasib¹¹³, S. Hassani¹³⁶, S. Haug¹⁸, R. Hauser⁹¹, L. Hauswald⁴⁶, M. Havranek¹²⁷, C. M. Hawkes¹⁹, R. J. Hawkins³², D. Hayakawa¹⁵⁷, D. Hayden⁹¹, C. P. Hays¹²⁰, J. M. Hays⁷⁷, H. S. Hayward⁷⁵, S. J. Haywood¹³¹, S. J. Head¹⁹, T. Heck⁸⁴, V. Hedberg⁸², L. Heelan⁸, S. Heim¹²², T. Heim¹⁶, B. Heinemann¹⁶, J. J. Heinrich¹⁰⁰, L. Heinrich¹¹⁰, C. Heinz⁵⁴, J. Hejbal¹²⁷, L. Helary³², S. Hellman^{146a,146b}, C. Helsens³², J. Henderson¹²⁰, R. C. W. Henderson⁷³, Y. Heng¹⁷², S. Henkelmann¹⁶⁷, A. M. Henriques Correia³², S. Henrot-Versille¹¹⁷, G. H. Herbert¹⁷, H. Herde²⁵, V. Herget¹⁷³, Y. Hernández Jiménez¹⁶⁶, G. Herten⁵⁰, R. Hertenberger¹⁰⁰, L. Hervas³², G. G. Hesketh⁷⁹, N. P. Hessey¹⁰⁷, J. W. Hetherly⁴², R. Hickling⁷⁷, E. Higón-Rodriguez¹⁶⁶, E. Hill¹⁶⁸, J. C. Hill³⁰, K. H. Hiller⁴⁴, S. J. Hillier¹⁹, I. Hinchliffe¹⁶, E. Hines¹²², R. R. Hinman¹⁶, M. Hirose⁵⁰, D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁸, N. Hod^{159a}, M. C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker³², M. R. Hoefkamp¹⁰⁵, F. Hoenic¹⁰⁰, D. Hohn²³, T. R. Holmes¹⁶, M. Homann⁴⁵, T. Honda⁶⁷, T. M. Hong¹²⁵, B. H. Hooberman¹⁶⁵, W. H. Hopkins¹¹⁶, Y. Horii¹⁰³, A. J. Horton¹⁴², J.-Y. Hostachy⁵⁷, S. Hou¹⁵¹, A. Hoummada^{135a}, J. Howarth⁴⁴, J. Hoya⁷², M. Hrabovsky¹¹⁵, I. Hristova¹⁷, J. Hrivnac¹¹⁷, T. Hryn'ova⁵, A. Hrynevich⁹⁴, C. Hsu^{145c}, P. J. Hsu^{151,t}, S. -C. Hsu¹³⁸, Q. Hu^{35b}, S. Hu^{35e}, Y. Huang⁴⁴, Z. Hubacek¹²⁸, F. Hubaut⁸⁶, F. Huegging²³, T. B. Huffman¹²⁰, E. W. Hughes³⁷, G. Hughes⁷³, M. Huhtinen³², P. Huo¹⁴⁸,

- N. Huseynov^{66,b}, J. Huston⁹¹, J. Huth⁵⁸, G. Iacobucci⁵¹, G. Iakovidis²⁷, I. Ibragimov¹⁴¹, L. Iconomidou-Fayard¹¹⁷, E. Ideal¹⁷⁵, Z. Idrissi^{135e}, P. Iengo³², O. Igonkina^{107,u}, T. Iizawa¹⁷⁰, Y. Ikegami⁶⁷, M. Ikeno⁶⁷, Y. Ilchenko^{11,v}, D. Iliadis¹⁵⁴, N. Ilic¹⁴³, T. Ince¹⁰¹, G. Introzzi^{121a,121b}, P. Ioannou^{9,*}, M. Iodice^{134a}, K. Iordanidou³⁷, V. Ippolito⁵⁸, N. Ishijima¹¹⁸, M. Ishino¹⁵⁵, M. Ishitsuka¹⁵⁷, R. Ishmukhametov¹¹¹, C. Issever¹²⁰, S. Istin^{20a}, F. Ito¹⁶⁰, J. M. Iturbe Ponce⁸⁵, R. Iuppa^{133a,133b}, W. Iwanski⁶³, H. Iwasaki⁶⁷, J. M. Izen⁴³, V. Izzo^{104a}, S. Jabbar³, B. Jackson¹²², P. Jackson¹, V. Jain², K. B. Jakobi⁸⁴, K. Jakobs⁵⁰, S. Jakobsen³², T. Jakoubek¹²⁷, D. O. Jamin¹¹⁴, D. K. Jana⁸⁰, R. Jansky⁶³, J. Janssen²³, M. Janus⁵⁶, G. Jarlskog⁸², N. Javadov^{66,b}, T. Javůrek⁵⁰, F. Jeanneau¹³⁶, L. Jeanty¹⁶, G. -Y. Jeng¹⁵⁰, D. Jennens⁸⁹, P. Jenni^{50,w}, C. Jeske¹⁶⁹, S. Jézéquel⁵, H. Ji¹⁷², J. Jia¹⁴⁸, H. Jiang⁶⁵, Y. Jiang^{35b}, S. Jiggins⁷⁹, J. Jimenez Pena¹⁶⁶, S. Jin^{35a}, A. Jinaru^{28b}, O. Jinnouchi¹⁵⁷, H. Jivan^{145c}, P. Johansson¹³⁹, K. A. Johns⁷, W. J. Johnson¹³⁸, K. Jon-And^{146a,146b}, G. Jones¹⁶⁹, R. W. L. Jones⁷³, S. Jones⁷, T. J. Jones⁷⁵, J. Jongmanns^{59a}, P. M. Jorge^{126a,126b}, J. Jovicevic^{159a}, X. Ju¹⁷², A. Juste Rozas^{13,r}, M. K. Köhler¹⁷¹, A. Kaczmarek⁴¹, M. Kado¹¹⁷, H. Kagan¹¹¹, M. Kagan¹⁴³, S. J. Kahn⁸⁶, T. Kaji¹⁷⁰, E. Kajomovitz⁴⁷, C. W. Kalderon¹²⁰, A. Kaluza⁸⁴, S. Kama⁴², A. Kamenshchikov¹³⁰, N. Kanaya¹⁵⁵, S. Kaneti³⁰, L. Kanjir⁷⁶, V. A. Kantserov⁹⁸, J. Kanzaki⁶⁷, B. Kaplan¹¹⁰, L. S. Kaplan¹⁷², A. Kapliy³³, D. Kar^{145c}, K. Karakostas¹⁰, A. Karamaoun³, N. Karastathis¹⁰, M. J. Kareem⁵⁶, E. Karentzos¹⁰, M. Karnevskiy⁸⁴, S. N. Karpov⁶⁶, Z. M. Karpova⁶⁶, K. Karthik¹¹⁰, V. Kartvelishvili⁷³, A. N. Karyukhin¹³⁰, K. Kasahara¹⁶⁰, L. Kashif¹⁷², R. D. Kass¹¹¹, A. Kastanas¹⁵, Y. Kataoka¹⁵⁵, C. Kato¹⁵⁵, A. Katre⁵¹, J. Katzy⁴⁴, K. Kawagoe⁷¹, T. Kawamoto¹⁵⁵, G. Kawamura⁵⁶, V. F. Kazanin^{109,c}, R. Keeler¹⁶⁸, R. Kehoe⁴², J. S. Keller⁴⁴, J. J. Kempster⁷⁸, K. Kentaro¹⁰³, H. Keoshkerian¹⁵⁸, O. Kepka¹²⁷, B. P. Kerševan⁷⁶, S. Kersten¹⁷⁴, R. A. Keyes⁸⁸, M. Khader¹⁶⁵, F. Khalil-zada¹², A. Khanov¹¹⁴, A. G. Kharlamov^{109,c}, T. Kharlamova¹⁰⁹, T. J. Khoo⁵¹, V. Khovanskij⁹⁷, E. Khramov⁶⁶, J. Khubua^{53b,x}, S. Kido⁶⁸, C. R. Kilby⁷⁸, H. Y. Kim⁸, S. H. Kim¹⁶⁰, Y. K. Kim³³, N. Kimura¹⁵⁴, O. M. Kind¹⁷, B. T. King⁷⁵, M. King¹⁶⁶, J. Kirk¹³¹, A. E. Kiryunin¹⁰¹, T. Kishimoto¹⁵⁵, D. Kisielewska^{40a}, F. Kiss⁵⁰, K. Kiuchi¹⁶⁰, O. Kivernyk¹³⁶, E. Kladiva^{144b}, M. H. Klein³⁷, M. Klein⁷⁵, U. Klein⁷⁵, K. Kleinknecht⁸⁴, P. Klimek¹⁰⁸, A. Klimentov²⁷, R. Klingenberg⁴⁵, J. A. Klinger¹³⁹, T. Klioutchnikova³², E. -E. Kluge^{59a}, P. Kluit¹⁰⁷, S. Kluth¹⁰¹, J. Knapik⁴¹, E. Kneringer⁶³, E. B. F. G. Knoop⁸⁶, A. Knue⁵⁵, A. Kobayashi¹⁵⁵, D. Kobayashi¹⁵⁷, T. Kobayashi¹⁵⁵, M. Kobel⁴⁶, M. Kocian¹⁴³, P. Kodys¹²⁹, N. M. Koehler¹⁰¹, T. Koffas³¹, E. Koffeman¹⁰⁷, T. Koi¹⁴³, H. Kolanoski¹⁷, M. Kolb^{59b}, I. Koletsou⁵, A. A. Komar^{96,*}, Y. Komori¹⁵⁵, T. Kondo⁶⁷, N. Kondrashova⁴⁴, K. Köneke⁵⁰, A. C. König¹⁰⁶, T. Kono^{67,y}, R. Konoplich^{110,z}, N. Konstantinidis⁷⁹, R. Kopeliansky⁶², S. Koperny^{40a}, L. Köpke⁸⁴, A. K. Kopp⁵⁰, K. Korcyl⁴¹, K. Kordas¹⁵⁴, A. Korn⁷⁹, A. A. Korol^{109,c}, I. Korolkov¹³, E. V. Korolkova¹³⁹, O. Kortner¹⁰¹, S. Kortner¹⁰¹, T. Kosek¹²⁹, V. V. Kostyukhin²³, A. Kotwal⁴⁷, A. Kourkumeli-Charalampidi^{121a,121b}, C. Kourkumelis⁹, V. Kouskoura²⁷, A. B. Kowalewska⁴¹, R. Kowalewski¹⁶⁸, T. Z. Kowalski^{40a}, C. Kozakai¹⁵⁵, W. Kozanecki¹³⁶, A. S. Kozhin¹³⁰, V. A. Kramarenko⁹⁹, G. Kramberger⁷⁶, D. Krasnopevtsev⁹⁸, M. W. Krasny⁸¹, A. Krasznahorkay³², A. Kravchenko²⁷, M. Kretz^{59c}, J. Kretzschmar⁷⁵, K. Kreutzfeldt⁵⁴, P. Krieger¹⁵⁸, K. Krizka³³, K. Kroeninger⁴⁵, H. Kroha¹⁰¹, J. Kroll¹²², J. Kroseberg²³, J. Krstic¹⁴, U. Kruchonak⁶⁶, H. Krüger²³, N. Krumnack⁶⁵, A. Kruse¹⁷², M. C. Kruse⁴⁷, M. Kruskal²⁴, T. Kubota⁸⁹, H. Kucuk⁷⁹, S. Kудay^{4b}, J. T. Kuechler¹⁷⁴, S. Kuehn⁵⁰, A. Kugel^{59c}, F. Kuger¹⁷³, A. Kuhl¹³⁷, T. Kuhl⁴⁴, V. Kukhtin⁶⁶, R. Kukla¹³⁶, Y. Kulchitsky⁹³, S. Kuleshov^{34b}, M. Kuna^{132a,132b}, T. Kunigo⁶⁹, A. Kupco¹²⁷, H. Kurashige⁶⁸, Y. A. Kurochkin⁹³, V. Kus¹²⁷, E. S. Kuwertz¹⁶⁸, M. Kuze¹⁵⁷, J. Kvita¹¹⁵, T. Kwan¹⁶⁸, D. Kyriazopoulos¹³⁹, A. La Rosa¹⁰¹, J. L. La Rosa Navarro^{26d}, L. La Rotonda^{39a,39b}, C. Lacasta¹⁶⁶, F. Lacava^{132a,132b}, J. Lacey³¹, H. Lacker¹⁷, D. Lacour⁸¹, V. R. Lacuesta¹⁶⁶, E. Ladygin⁶⁶, R. Lafaye⁵, B. Laforge⁸¹, T. Lagouri¹⁷⁵, S. Lai⁵⁶, S. Lammers⁶², W. Lampl⁷, E. Lançon¹³⁶, U. Landgraf⁵⁰, M. P. J. Landon⁷⁷, M. C. Lanfermann⁵¹, V. S. Lang^{59a}, J. C. Lange¹³, A. J. Lankford¹⁶², F. Lanni²⁷, K. Lantzsche²³, A. Lanza^{121a}, S. Laplace⁸¹, C. Lapoire³², J. F. Laporte¹³⁶, T. Lari^{92a}, F. Lasagni Manghi^{22a,22b}, M. Lassnig³², P. Laurelli⁴⁹, W. Lavrijsen¹⁶, A. T. Law¹³⁷, P. Laycock⁷⁵, T. Lazovich⁵⁸, M. Lazzaroni^{92a,92b}, B. Le⁸⁹, O. Le Dortz⁸¹, E. Le Guirrec⁸⁶, E. P. Le Quilleuc¹³⁶, M. LeBlanc¹⁶⁸, T. LeCompte⁶, F. Ledroit-Guillon⁵⁷, C. A. Lee²⁷, S. C. Lee¹⁵¹, L. Lee¹, B. Lefebvre⁸⁸, G. Lefebvre⁸¹, M. Lefebvre¹⁶⁸, F. Legger¹⁰⁰, C. Leggett¹⁶, A. Lehan⁷⁵, G. Lehmann Miotto³², X. Lei⁷, W. A. Light³¹, A. Leisos^{154,aa}, A. G. Leister¹⁷⁵, M. A. L. Leite^{26d}, R. Leitner¹²⁹, D. Lellouch¹⁷¹, B. Lemmer⁵⁶, K. J. C. Leney⁷⁹, T. Lenz²³, B. Lenzi³², R. Leone⁷, S. Leone^{124a,124b}, C. Leonidopoulos⁴⁸, S. Leontsinis¹⁰, G. Lerner¹⁴⁹, C. Leroy⁹⁵, A. A. J. Lesage¹³⁶, C. G. Lester³⁰, M. Levchenko¹²³, J. Levêque⁵, D. Levin⁹⁰, L. J. Levinson¹⁷¹, M. Levy¹⁹, D. Lewis⁷⁷, A. M. Leyko²³, M. Leyton⁴³, B. Li^{35b,o}, C. Li^{35b}, H. Li¹⁴⁸, H. L. Li³³, L. Li⁴⁷, L. Li^{35e}, Q. Li^{35a}, S. Li⁴⁷, X. Li⁸⁵, Y. Li¹⁴¹, Z. Liang^{35a}, B. Liberti^{133a}, A. Liblong¹⁵⁸, P. Lichard³², K. Lie¹⁶⁵, J. Liebal²³, W. Liebig¹⁵, A. Limosani¹⁵⁰, S. C. Lin^{151,ab}, T. H. Lin⁸⁴, B. E. Lindquist¹⁴⁸, A. E. Lioni⁵¹, E. Lipeles¹²², A. Lipniacka¹⁵, M. Lisovyi^{59b}, T. M. Liss¹⁶⁵, A. Lister¹⁶⁷, A. M. Litke¹³⁷, B. Liu^{151,ac}, D. Liu¹⁵¹, H. Liu⁹⁰, H. Liu²⁷, J. Liu⁸⁶, J. B. Liu^{35b}, K. Liu⁸⁶, L. Liu¹⁶⁵, M. Liu⁴⁷, M. Liu^{35b}, Y. L. Liu^{35b}, Y. Liu^{35b}, M. Livan^{121a,121b}, A. Lleres⁵⁷, J. Llorente Merino^{35a}, S. L. Lloyd⁷⁷, F. Lo Sterzo¹⁵¹, E. M. Lobodzinska⁴⁴, P. Loch⁷, W. S. Lockman¹³⁷, F. K. Loebinger⁸⁵, A. E. Loevschall-Jensen³⁸, K. M. Loew²⁵, A. Loginov^{175,*}, T. Lohse¹⁷, K. Lohwasser⁴⁴, M. Lokajicek¹²⁷, B. A. Long²⁴, J. D. Long¹⁶⁵, R. E. Long⁷³, L. Longo^{74a,74b}

K. A. Looper¹¹¹, J. A. López^{34b}, D. Lopez Mateos⁵⁸, B. Lopez Paredes¹³⁹, I. Lopez Paz¹³, A. Lopez Solis⁸¹, J. Lorenz¹⁰⁰, N. Lorenzo Martinez⁶², M. Losada²¹, P. J. Lösel¹⁰⁰, X. Lou^{35a}, A. Lounis¹¹⁷, J. Love⁶, P. A. Love⁷³, H. Lu^{61a}, N. Lu⁹⁰, H. J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁷, C. Luedtke⁵⁰, F. Luehring⁶², W. Lukas⁶³, L. Luminari^{132a}, O. Lundberg^{146a,146b}, B. Lund-Jensen¹⁴⁷, P. M. Luzzi⁸¹, D. Lynn²⁷, R. Lysak¹²⁷, E. Lytken⁸², V. Lyubushkin⁶⁶, H. Ma²⁷, L. L. Ma^{35d}, Y. Ma^{35d}, G. Maccarrone⁴⁹, A. Macchiolo¹⁰¹, C. M. Macdonald¹³⁹, B. Maček⁷⁶, J. Machado Miguens^{122,126b}, D. Madaffari⁸⁶, R. Madar³⁶, H. J. Maddocks¹⁶⁴, W. F. Mader⁴⁶, A. Madsen⁴⁴, J. Maeda⁶⁸, S. Maeland¹⁵, T. Maeno²⁷, A. Maevskiy⁹⁹, E. Magradze⁵⁶, J. Mahlstedt¹⁰⁷, C. Maiani¹¹⁷, C. Maidantchik^{26a}, A. A. Maier¹⁰¹, T. Maier¹⁰⁰, A. Maio^{126a,126b,126d}, S. Majewski¹¹⁶, Y. Makida⁶⁷, N. Makovec¹¹⁷, B. Malaescu⁸¹, Pa. Malecki⁴¹, V. P. Maleev¹²³, F. Malek⁵⁷, U. Mallik⁶⁴, D. Malon⁶, C. Malone¹⁴³, C. Malone³⁰, S. Maltezos¹⁰, S. Malyukov³², J. Mamuzic¹⁶⁶, G. Mancini⁴⁹, L. M. andelli^{92a}, I. Mandić⁷⁶, J. Maneira^{126a,126b}, L. Manhaes de Andrade Filho^{26b}, J. Manjarres Ramos^{159b}, A. Mann¹⁰⁰, A. Manousos³², B. Mansoulie¹³⁶, J. D. Mansour^{35a}, R. Mantifel⁸⁸, M. Mantoani⁵⁶, S. Manzoni^{92a,92b}, L. Mapelli³², G. Marceca²⁹, L. March⁵¹, G. Marchiori⁸¹, M. Marcisovsky¹²⁷, M. Marjanovic¹⁴, D. E. Marley⁹⁰, F. Marroquim^{26a}, S. P. Marsden⁸⁵, Z. Marshall¹⁶, S. Marti-Garcia¹⁶⁶, B. Martin⁹¹, T. A. Martin¹⁶⁹, V. J. Martin⁴⁸, B. Martin dit Latour¹⁵, M. Martinez^{13,r}, V. I. Martinez Outschoorn¹⁶⁵, S. Martin-Haugh¹³¹, V. S. Martoiu^{28b}, A. C. Martyniuk⁷⁹, M. Marx¹³⁸, A. Marzin³², L. Masetti⁸⁴, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁶, J. Masik⁸⁵, A. L. Maslennikov^{109,c}, I. Massa^{22a,22b}, L. Massa^{22a,22b}, P. Mastrandrea⁵, A. Mastroberardino^{39a,39b}, T. Masubuchi¹⁵⁵, P. Mättig¹⁷⁴, J. Mattmann⁸⁴, J. Maurer^{28b}, S. J. Maxfield⁷⁵, D. A. Maximov^{109,c}, R. Mazini¹⁵¹, S. M. Mazza^{92a,92b}, N. C. Mc Fadden¹⁰⁵, G. Mc Goldrick¹⁵⁸, S. P. Mc Kee⁹⁰, A. McCann⁹⁰, R. L. McCarthy¹⁴⁸, T. G. McCarthy¹⁰¹, L. I. McClymont⁷⁹, E. F. McDonald⁸⁹, J. A. Mcfayden⁷⁹, G. Mchedlidze⁵⁶, S. J. McMahon¹³¹, R. A. McPherson^{168,l}, M. Medinnis⁴⁴, S. Meehan¹³⁸, S. Mehlhase¹⁰⁰, A. Mehta⁷⁵, K. Meier^{59a}, C. Meineck¹⁰⁰, B. Meirose⁴³, D. Melini¹⁶⁶, B. R. Mellado Garcia^{145c}, M. Melo^{144a}, F. Meloni¹⁸, A. Mengarelli^{22a,22b}, S. Menke¹⁰¹, E. Meoni¹⁶¹, S. Mergelmeyer¹⁷, P. Mermod⁵¹, L. Merola^{104a,104b}, C. Meroni^{92a}, F. S. Merritt³³, A. Messina^{132a,132b}, J. Metcalfe⁶, A. S. Mete¹⁶², C. Meyer⁸⁴, C. Meyer¹²², J.-P. Meyer¹³⁶, J. Meyer¹⁰⁷, H. Meyer Zu Theenhausen^{59a}, F. Miano¹⁴⁹, R. P. Middleton¹³¹, S. Miglioranza^{52a,52b}, L. Mijović⁴⁸, G. Mikenberg¹⁷¹, M. Mikestikova¹²⁷, M. Mikuz⁷⁶, M. Milesi⁸⁹, A. Milic⁶³, D. W. Miller³³, C. Mills⁴⁸, A. Milov¹⁷¹, D. A. Milstead^{146a,146b}, A. A. Minaenko¹³⁰, Y. Minami¹⁵⁵, I. A. Minashvili⁶⁶, A. I. Mincer¹¹⁰, B. Mindur^{40a}, M. Mineev⁶⁶, Y. Minegishi¹⁵⁵, Y. Ming¹⁷², L. M. Mir¹³, K. P. Mistry¹²², T. Mitani¹⁷⁰, J. Mitrevski¹⁰⁰, V. A. Mitsou¹⁶⁶, A. Miucci¹⁸, P. S. Miyagawa¹³⁹, J. U. Mjörnmark⁸², M. Mlynarikova¹²⁹, T. Moa^{146a,146b}, K. Mochizuki⁹⁵, S. Mohapatra³⁷, S. Molander^{146a,146b}, R. Moles-Valls²³, R. Monden⁶⁹, M. C. Mondragon⁹¹, K. Mönig⁴⁴, J. Monk³⁸, E. Monnier⁸⁶, A. Montalbano¹⁴⁸, J. Montejo Berlingen³², F. Monticelli⁷², S. Monzani^{92a,92b}, R. W. Moore³, N. Morange¹¹⁷, D. Moreno²¹, M. Moreno Llácer⁵⁶, P. Morettini^{52a}, S. Morgenstern³², D. Mori¹⁴², T. Mori¹⁵⁵, M. Morii⁵⁸, M. Morinaga¹⁵⁵, V. Morisbak¹¹⁹, S. Moritz⁸⁴, A. K. Morley¹⁵⁰, G. Mornacchi³², J. D. Morris⁷⁷, S. S. Mortensen³⁸, L. Morvaj¹⁴⁸, M. Mosidze^{53b}, J. Moss^{143,ad}, K. Motohashi¹⁵⁷, R. Mount¹⁴³, E. Mountricha²⁷, E. J. W. Moyse⁸⁷, S. Muanza⁸⁶, R. D. Mudd¹⁹, F. Mueller¹⁰¹, J. Mueller¹²⁵, R. S. P. Mueller¹⁰⁰, T. Mueller³⁰, D. Muenstermann⁷³, P. Mullen⁵⁵, G. A. Mullier¹⁸, F. J. Munoz Sanchez⁸⁵, J. A. Murillo Quijada¹⁹, W. J. Murray^{131,169}, H. Musheghyan⁵⁶, M. Muškinja⁷⁶, A. G. Myagkov^{130,ae}, M. Myska¹²⁸, B. P. Nachman¹⁴³, O. Nackenhorst⁵¹, K. Nagai¹²⁰, R. Nagai^{67,y}, K. Nagano⁶⁷, Y. Nagasaka⁶⁰, K. Nagata¹⁶⁰, M. Nagel⁵⁰, E. Nagy⁸⁶, A. M. Nairz³², Y. Nakahama¹⁰³, K. Nakamura⁶⁷, T. Nakamura¹⁵⁵, I. Nakano¹¹², H. Namasivayam⁴³, R. F. Naranjo Garcia⁴⁴, R. Narayan¹¹, D. I. Narrias Villar^{59a}, I. Naryshkin¹²³, T. Naumann⁴⁴, G. Navarro²¹, R. Nayyar⁷, H. A. Neal⁹⁰, P. Yu. Nechaeva⁹⁶, T. J. Neep⁸⁵, A. Negri^{121a,121b}, M. Negrini^{22a}, S. Nektarijevic¹⁰⁶, C. Nellist¹¹⁷, A. Nelson¹⁶², S. Nemecek¹²⁷, P. Nemethy¹¹⁰, A. A. Nepomuceno^{26a}, M. Nessi^{32,af}, M. S. Neubauer¹⁶⁵, M. Neumann¹⁷⁴, R. M. Neves¹¹⁰, P. Nevski²⁷, P. R. Newman¹⁹, D. H. Nguyen⁶, T. Nguyen Manh⁹⁵, R. B. Nickerson¹²⁰, R. Nicolaïdou¹³⁶, J. Nielsen¹³⁷, A. Nikiforov¹⁷, V. Nikolaenko^{130,ae}, I. Nikolic-Audit⁸¹, K. Nikolopoulos¹⁹, J. K. Nilsen¹¹⁹, P. Nilsson²⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, R. Nisius¹⁰¹, T. Nobe¹⁵⁵, M. Nomachi¹¹⁸, I. Nomidis³¹, T. Nooney⁷⁷, S. Norberg¹¹³, M. Nordberg³², N. Norjoharuddeen¹²⁰, O. Novgorodova⁴⁶, S. Nowak¹⁰¹, M. Nozaki⁶⁷, L. Nozka¹¹⁵, K. Ntekas¹⁶², E. Nurse⁷⁹, F. Nuti⁸⁹, F. O'grady⁷, D. C. O'Neil¹⁴², A. A. O'Rourke⁴⁴, V. O'Shea⁵⁵, F. G. Oakham^{31,d}, H. Oberlack¹⁰¹, T. Obermann²³, J. Ocariz⁸¹, A. Ochi⁶⁸, I. Ochoa³⁷, J. P. Ochoa-Ricoux^{34a}, S. Oda⁷¹, S. Odaka⁶⁷, H. Ogren⁶², A. Oh⁸⁵, S. H. Oh⁴⁷, C. C. Ohm¹⁶, H. Ohman¹⁶⁴, H. Oide³², H. Okawa¹⁶⁰, Y. Okumura¹⁵⁵, T. Okuyama⁶⁷, A. Olariu^{28b}, L. F. Oleiro Seabra^{126a}, S. A. Olivares Pino⁴⁸, D. Oliveira Damazio²⁷, A. Olszewski⁴¹, J. Olszowska⁴¹, A. Onofre^{126a,126e}, K. Onogi¹⁰³, P. U. E. Onyisi^{11,v}, M. J. Oreglia³³, Y. Oren¹⁵³, D. Orestano^{134a,134b}, N. Orlando^{61b}, R. S. Orr¹⁵⁸, B. Osculati^{52a,52b,*}, R. Ospanov⁸⁵, G. Otero y Garzon²⁹, H. Otono⁷¹, M. Ouchrif^{135d}, F. Ould-Saada¹¹⁹, A. Ouraou¹³⁶, K. P. Oussoren¹⁰⁷, Q. Ouyang^{35a}, M. Owen⁵⁵, R. E. Owen¹⁹, V. E. Ozcan^{20a}, N. Ozturk⁸, K. Pachal¹⁴², A. Pacheco Pages¹³, L. Pacheco Rodriguez¹³⁶, C. Padilla Aranda¹³, M. Pagáčová⁵⁰, S. Pagan Griso¹⁶, M. Paganini¹⁷⁵, F. Paige²⁷, P. Pais⁸⁷, K. Pajchel¹¹⁹, G. Palacino^{159b}, S. Palazzo^{39a,39b}, S. Palestini³², M. Palka^{40b}, D. Pallin³⁶,

- E. St. Panagiotopoulou¹⁰, C. E. Pandini⁸¹, J. G. Panduro Vazquez⁷⁸, P. Pani^{146a,146b}, S. Panitkin²⁷, D. Pantea^{28b}, L. Paolozzi⁵¹, Th. D. Papadopoulos¹⁰, K. Papageorgiou¹⁵⁴, A. Paramonov⁶, D. Paredes Hernandez¹⁷⁵, A. J. Parker⁷³, M. A. Parker³⁰, K. A. Parker¹³⁹, F. Parodi^{52a,52b}, J. A. Parsons³⁷, U. Parzefall⁵⁰, V. R. Pascuzzi¹⁵⁸, E. Pasqualucci^{132a}, S. Passaggio^{52a}, Fr. Pastore⁷⁸, G. Pásztor^{31,ag}, S. Pataria¹⁷⁴, J. R. Pater⁸⁵, T. Pauly³², J. Pearce¹⁶⁸, B. Pearson¹¹³, L. E. Pedersen³⁸, M. Pedersen¹¹⁹, S. Pedraza Lopez¹⁶⁶, R. Pedro^{126a,126b}, S. V. Peleganchuk^{109,c}, O. Penc¹²⁷, C. Peng^{35a}, H. Peng^{35b}, J. Penwell⁶², B. S. Peralva^{26b}, M. M. Perego¹³⁶, D. V. Perepelitsa²⁷, E. Perez Codina^{159a}, L. Perini^{92a,92b}, H. Pernegger³², S. Perrella^{104a,104b}, R. Peschke⁴⁴, V. D. Peshekhonov⁶⁶, K. Peters⁴⁴, R. F. Y. Peters⁸⁵, B. A. Petersen³², T. C. Petersen³⁸, E. Petit⁵⁷, A. Petridis¹, C. Petridou¹⁵⁴, P. Petroff¹¹⁷, E. Petrolo^{132a}, M. Petrov¹²⁰, F. Petrucci^{134a,134b}, N. E. Pettersson⁸⁷, A. Peyaud¹³⁶, R. Pezoa^{34b}, P. W. Phillips¹³¹, G. Piacquadio^{143,ah}, E. Pianori¹⁶⁹, A. Picazio⁸⁷, E. Piccaro⁷⁷, M. Piccinini^{22a,22b}, M. A. Pickering¹²⁰, R. Piegai²⁹, J. E. Pilcher³³, A. D. Pilkington⁸⁵, A. W. J. Pin⁸⁵, M. Pinamonti^{163a,163c,ai}, J. L. Pinfold³, A. Pingel³⁸, S. Pires⁸¹, H. Pirumov⁴⁴, M. Pitt¹⁷¹, L. Plazak^{144a}, M. -A. Pleier²⁷, V. Pleskot⁸⁴, E. Plotnikova⁶⁶, P. Plucinski⁹¹, D. Pluth⁶⁵, R. Poettgen^{146a,146b}, L. Poggioli¹¹⁷, D. Pohl²³, G. Polesello^{121a}, A. Poley⁴⁴, A. Policicchio^{39a,39b}, R. Polifka¹⁵⁸, A. Polini^{22a}, C. S. Pollard⁵⁵, V. Polychronakos²⁷, K. Pommès³², L. Pontecorvo^{132a}, B. G. Pope⁹¹, G. A. Popeneciu^{28c}, A. Poppleton³², S. Pospisil¹²⁸, K. Potamianos¹⁶, I. N. Potrap⁶⁶, C. J. Potter³⁰, C. T. Potter¹¹⁶, G. Poulard³², J. Poveda³², V. Pozdnyakov⁶⁶, M. E. Pozo Astigarraga³², P. Pralavorio⁸⁶, A. Pranko¹⁶, S. Prell⁶⁵, D. Price⁸⁵, L. E. Price⁶, M. Primavera^{74a}, S. Prince⁸⁸, K. Prokofiev^{61c}, F. Prokoshin^{34b}, S. Protopopescu²⁷, J. Proudfoot⁶, M. Przybycien^{40a}, D. Puddu^{134a,134b}, M. Purohit^{27,aj}, P. Puzo¹¹⁷, J. Qian⁹⁰, G. Qin⁵⁵, Y. Qin⁸⁵, A. Quadt⁵⁶, W. B. Quayle^{163a,163b}, M. Queitsch-Maitland⁸⁵, D. Quilty⁵⁵, S. Raddum¹¹⁹, V. Radeka²⁷, V. Radescu¹²⁰, S. K. Radhakrishnan¹⁴⁸, P. Radloff¹¹⁶, P. Rados⁸⁹, F. Ragusa^{92a,92b}, G. Rahal¹⁷⁷, J. A. Raine⁸⁵, S. Rajagopalan²⁷, M. Rammensee³², C. Rangel-Smith¹⁶⁴, M. G. Ratti^{92a,92b}, F. Rauscher¹⁰⁰, S. Rave⁸⁴, T. Ravenscroft⁵⁵, I. Ravinovich¹⁷¹, M. Raymond³², A. L. Read¹¹⁹, N. P. Readioff⁷⁵, M. Reale^{74a,74b}, D. M. Rebuzzi^{121a,121b}, A. Redelbach¹⁷³, G. Redlinger²⁷, R. Reece¹³⁷, K. Reeves⁴³, L. Rehnisch¹⁷, J. Reichert¹²², A. Reiss⁸⁴, C. Rembser³², H. Ren^{35a}, M. Rescigno^{132a}, S. Resconi^{92a}, O. L. Rezanova^{109,c}, P. Reznicek¹²⁹, R. Rezvani⁹⁵, R. Richter¹⁰¹, S. Richter⁷⁹, E. Richter-Was^{40b}, O. Ricken²³, M. Ridel⁸¹, P. Rieck¹⁷, C. J. Riegel¹⁷⁴, J. Rieger⁵⁶, O. Rifki¹¹³, M. Rijssenbeek¹⁴⁸, A. Rimoldi^{121a,121b}, M. Rimoldi¹⁸, L. Rinaldi^{22a}, B. Ristic⁵¹, E. Ritsch³², I. Riu¹³, F. Rizatdinova¹¹⁴, E. Rizvi⁷⁷, C. Rizzi¹³, S. H. Robertson^{88,1}, A. Robichaud-Veronneau⁸⁸, D. Robinson³⁰, J. E. M. Robinson⁴⁴, A. Robson⁵⁵, C. Roda^{124a,124b}, Y. Rodina⁸⁶, A. Rodriguez Perez¹³, D. Rodriguez Rodriguez¹⁶⁶, S. Roe³², C. S. Rogan⁵⁸, O. Røhne¹¹⁹, A. Romaniouk⁹⁸, M. Romano^{22a,22b}, S. M. Romano Saez³⁶, E. Romero Adam¹⁶⁶, N. Rompotis¹³⁸, M. Ronzani⁵⁰, L. Roos⁸¹, E. Ros¹⁶⁶, S. Rosati^{132a}, K. Rosbach⁵⁰, P. Rose¹³⁷, N. -A. Rosien⁵⁶, V. Rossetti^{146a,146b}, E. Rossi^{104a,104b}, L. P. Rossi^{52a}, J. H. N. Rosten³⁰, R. Rosten¹³⁸, M. Rotaru^{28b}, I. Roth¹⁷¹, J. Rothberg¹³⁸, D. Rousseau¹¹⁷, A. Rozanov⁸⁶, Y. Rozen¹⁵², X. Ruan^{145c}, F. Rubbo¹⁴³, M. S. Rudolph¹⁵⁸, F. Rühr⁵⁰, A. Ruiz-Martinez³¹, Z. Rurikova⁵⁰, N. A. Rusakovich⁶⁶, A. Ruschke¹⁰⁰, H. L. Russell¹³⁸, J. P. Rutherford⁷, N. Ruthmann³², Y. F. Ryabov¹²³, M. Rybar¹⁶⁵, G. Rybkin¹¹⁷, S. Ryu⁶, A. Ryzhov¹³⁰, G. F. Rzehorz⁵⁶, A. F. Saavedra¹⁵⁰, G. Sabato¹⁰⁷, S. Sacerdoti²⁹, H. F-W. Sadrozinski¹³⁷, R. Sadykov⁶⁶, F. Safai Tehrani^{132a}, P. Saha¹⁰⁸, M. Sahinsoy^{59a}, M. Saimpert¹³⁶, T. Saito¹⁵⁵, H. Sakamoto¹⁵⁵, Y. Sakurai¹⁷⁰, G. Salamanna^{134a,134b}, A. Salamon^{133a,133b}, J. E. Salazar Loyola^{34b}, D. Salek¹⁰⁷, P. H. Sales De Bruin¹³⁸, D. Salihagic¹⁰¹, A. Salnikov¹⁴³, J. Salt¹⁶⁶, D. Salvatore^{39a,39b}, F. Salvatore¹⁴⁹, A. Salvucci^{61a}, A. Salzburger³², D. Sammel⁵⁰, D. Sampsonidis¹⁵⁴, A. Sanchez^{104a,104b}, J. Sánchez¹⁶⁶, V. Sanchez Martinez¹⁶⁶, H. Sandaker¹¹⁹, R. L. Sandbach⁷⁷, H. G. Sander⁸⁴, M. Sandhoff¹⁷⁴, C. Sandoval²¹, D. P. C. Sankey¹³¹, M. Sannino^{52a,52b}, A. Sansoni⁴⁹, C. Santoni³⁶, R. Santonico^{133a,133b}, H. Santos^{126a}, I. Santoyo Castillo¹⁴⁹, K. Sapp¹²⁵, A. Sapronov⁶⁶, J. G. Saraiva^{126a,126d}, B. Sarrazin²³, O. Sasaki⁶⁷, K. Sato¹⁶⁰, E. Sauvan⁵, G. Savage⁷⁸, P. Savard^{158,d}, N. Savic¹⁰¹, C. Sawyer¹³¹, L. Sawyer^{80,q}, J. Saxon³³, C. Sbarra^{22a}, A. Sbrizzi^{22a,22b}, T. Scanlon⁷⁹, D. A. Scannicchio¹⁶², M. Scarcella¹⁵⁰, V. Scarfone^{39a,39b}, J. Schaarschmidt¹⁷¹, P. Schacht¹⁰¹, B. M. Schachtner¹⁰⁰, D. Schaefer³², L. Schaefer¹²², R. Schaefer⁴⁴, J. Schaeffer⁸⁴, S. Schaepe²³, S. Schaetzel^{59b}, U. Schäfer⁸⁴, A. C. Schaffer¹¹⁷, D. Schaile¹⁰⁰, R. D. Schamberger¹⁴⁸, V. Scharf^{59a}, V. A. Schegelsky¹²³, D. Scheirich¹²⁹, M. Schernau¹⁶², C. Schiavi^{52a,52b}, S. Schier¹³⁷, C. Schillo⁵⁰, M. Schioppa^{39a,39b}, S. Schlenker³², K. R. Schmidt-Sommerfeld¹⁰¹, K. Schmieden³², C. Schmitt⁸⁴, S. Schmitt⁴⁴, S. Schmitz⁸⁴, B. Schneider^{159a}, U. Schnoor⁵⁰, L. Schoeffel¹³⁶, A. Schoening^{59b}, B. D. Schoenrock⁹¹, E. Schopf²³, M. Schott⁸⁴, J. F. P. Schouwenberg¹⁰⁶, J. Schovancova⁸, S. Schramm⁵¹, M. Schreyer¹⁷³, N. Schuh⁸⁴, A. Schulte⁸⁴, M. J. Schultens²³, H. -C. Schultz-Coulon^{59a}, H. Schulz¹⁷, M. Schumacher⁵⁰, B. A. Schumm¹³⁷, Ph. Schune¹³⁶, A. Schwartzman¹⁴³, T. A. Schwarz⁹⁰, H. Schweiger⁸⁵, Ph. Schwemling¹³⁶, R. Schwienhorst⁹¹, J. Schwindling¹³⁶, T. Schwindt²³, G. Sciolla²⁵, F. Scuri^{124a,124b}, F. Scutti⁸⁹, J. Searcy⁹⁰, P. Seema²³, S. C. Seidel¹⁰⁵, A. Seiden¹³⁷, F. Seifert¹²⁸, J. M. Seixas^{26a}, G. Sekhniaidze^{104a}, K. Sekhon⁹⁰, S. J. Sekula⁴², D. M. Seliverstov^{123,*}, N. Semprini-Cesari^{22a,22b}, C. Serfon¹¹⁹, L. Serin¹¹⁷, L. Serkin^{163a,163b}, M. Sessa^{134a,134b}, R. Seuster¹⁶⁸, H. Severini¹¹³, T. Sfiligoi⁷⁶, F. Sforza³², A. Sfyrla⁵¹, E. Shabalina⁵⁶, N. W. Shaikh^{146a,146b}, L. Y. Shan^{35a}, R. Shang¹⁶⁵, J. T. Shank²⁴, M. Shapiro¹⁶, P. B. Shatalov⁹⁷

K. Shaw^{163a,163b}, S. M. Shaw⁸⁵, A. Shcherbakova^{146a,146b}, C. Y. Shehu¹⁴⁹, P. Sherwood⁷⁹, L. Shi^{151,ak}, S. Shimizu⁶⁸, C. O. Shimmin¹⁶², M. Shimojima¹⁰², S. Shirabe⁷¹, M. Shiyakova^{66,al}, A. Shmeleva⁹⁶, D. Shoaleh Saadi⁹⁵, M. J. Shochet³³, S. Shojaii^{92a,92b}, D. R. Shope¹¹³, S. Shrestha¹¹¹, E. Shulga⁹⁸, M. A. Shupe⁷, P. Sicho¹²⁷, A. M. Sickles¹⁶⁵, P. E. Sidebo¹⁴⁷, O. Sidiropoulou¹⁷³, D. Sidorov¹¹⁴, A. Sidoti^{22a,22b}, F. Siegert⁴⁶, Dj. Sijacki¹⁴, J. Silva^{126a,126d}, S. B. Silverstein^{146a}, V. Simak¹²⁸, Lj. Simic¹⁴, S. Simion¹¹⁷, E. Simioni⁸⁴, B. Simmons⁷⁹, D. Simon³⁶, M. Simon⁸⁴, P. Sinervo¹⁵⁸, N. B. Sinev¹¹⁶, M. Sioli^{22a,22b}, G. Siragusa¹⁷³, S. Yu. Sivoklov⁹⁹, J. Sjölin^{146a,146b}, M. B. Skinner⁷³, H. P. Skottowe⁵⁸, P. Skubic¹¹³, M. Slater¹⁹, T. Slavicek¹²⁸, M. Slawinska¹⁰⁷, K. Sliwa¹⁶¹, R. Slovak¹²⁹, V. Smakhtin¹⁷¹, B. H. Smart⁵, L. Smestad¹⁵, J. Smiesko^{144a}, S. Yu. Smirnov⁹⁸, Y. Smirnov⁹⁸, L. N. Smirnova^{99,am}, O. Smirnova⁸², M. N. K. Smith³⁷, R. W. Smith³⁷, M. Smizanska⁷³, K. Smolek¹²⁸, A. A. Snesarev⁹⁶, I. M. Snyder¹¹⁶, S. Snyder²⁷, R. Sobie^{168,1}, F. Socher⁴⁶, A. Soffer¹⁵³, D. A. Soh¹⁵¹, G. Sokhrannyi⁷⁶, C. A. Solans Sanchez³², M. Solar¹²⁸, E. Yu. Soldatov⁹⁸, U. Soldevila¹⁶⁶, A. A. Solodkov¹³⁰, A. Soloshenko⁶⁶, O. V. Solovyanov¹³⁰, V. Solovyev¹²³, P. Sommer⁵⁰, H. Son¹⁶¹, H. Y. Song^{35b,an}, A. Sood¹⁶, A. Sopczak¹²⁸, V. Sopko¹²⁸, V. Sorin¹³, D. Sosa^{59b}, C. L. Sotiropoulou^{124a,124b}, R. Soualah^{163a,163c}, A. M. Soukharev^{109,c}, D. South⁴⁴, B. C. Sowden⁷⁸, S. Spagnolo^{74a,74b}, M. Spalla^{124a,124b}, M. Spangenberg¹⁶⁹, F. Spanò⁷⁸, D. Sperlich¹⁷, F. Spettel¹⁰¹, R. Spighi^{22a}, G. Spigo³², L. A. Spiller⁸⁹, M. Spousta¹²⁹, R. D. St. Denis^{55,*}, A. Stabile^{92a}, R. Stamen^{59a}, S. Stamm¹⁷, E. Stanecka⁴¹, R. W. Stanek⁶, C. Stancu^{134a}, M. Stancu-Bellu⁴⁴, M. M. Stanitzki⁴⁴, S. Stapnes¹¹⁹, E. A. Starchenko¹³⁰, G. H. Stark³³, J. Stark⁵⁷, P. Staroba¹²⁷, P. Starovoitov^{59a}, S. Stärz³², R. Staszewski⁴¹, P. Steinberg²⁷, B. Stelzer¹⁴², H. J. Stelzer³², O. Stelzer-Chilton^{159a}, H. Stenzel⁵⁴, G. A. Stewart⁵⁵, J. A. Stillings²³, M. C. Stockton⁸⁸, M. Stoebe⁸⁸, G. Stoicea^{28b}, P. Stolte⁵⁶, S. Stonjek¹⁰¹, A. R. Stradling⁸, A. Straessner⁴⁶, M. E. Stramaglia¹⁸, J. Strandberg¹⁴⁷, S. Strandberg^{146a,146b}, A. Strandlie¹¹⁹, M. Strauss¹¹³, P. Strizenec^{144b}, R. Ströhmer¹⁷³, D. M. Strom¹¹⁶, R. Stroynowski⁴², A. Strubig¹⁰⁶, S. A. Stucci¹⁵, B. Stugu¹⁵, N. A. Styles⁴⁴, D. Su¹⁴³, J. Su¹²⁵, S. Suchek^{59a}, Y. Sugaya¹¹⁸, M. Suk¹²⁸, V. V. Sulin⁹⁶, S. Sultansoy^{4c}, T. Sumida⁶⁹, S. Sun⁵⁸, X. Sun^{35a}, J. E. Sundermann⁵⁰, K. Suruliz¹⁴⁹, G. Susinno^{39a,39b}, M. R. Sutton¹⁴⁹, S. Suzuki⁶⁷, M. Svatos¹²⁷, M. Swiatlowski³³, I. Sykora^{144a}, T. Sykora¹²⁹, D. Ta⁵⁰, C. Taccini^{134a,134b}, K. Tackmann⁴⁴, J. Taenzer¹⁵⁸, A. Taffard¹⁶², R. Tafirout^{159a}, N. Taiblum¹⁵³, H. Takai²⁷, R. Takashima⁷⁰, T. Takeshita¹⁴⁰, Y. Takubo⁶⁷, M. Talby⁸⁶, A. A. Talyshv^{109,c}, K. G. Tan⁸⁹, J. Tanaka¹⁵⁵, M. Tanaka¹⁵⁷, R. Tanaka¹¹⁷, S. Tanaka⁶⁷, R. Tanioka⁶⁸, B. B. Tannenwald¹¹¹, S. Tapia Araya^{34b}, S. Tapprogge⁸⁴, S. Tarem¹⁵², G. F. Tartarelli^{92a}, P. Tas¹²⁹, M. Tasevsky¹²⁷, T. Tashiro⁶⁹, E. Tassi^{39a,39b}, A. Tavares Delgado^{126a,126b}, Y. Tayalati^{135e}, A. C. Taylor¹⁰⁵, G. N. Taylor⁸⁹, P. T. E. Taylor⁸⁹, W. Taylor^{159b}, F. A. Teischinger³², P. Teixeira-Dias⁷⁸, K. K. Temming⁵⁰, D. Temple¹⁴², H. Ten Kate³², P. K. Teng¹⁵¹, J. J. Teoh¹¹⁸, F. Tepel¹⁷⁴, S. Terada⁶⁷, K. Terashi¹⁵⁵, J. Terron⁸³, S. Terzo¹³, M. Testa⁴⁹, R. J. Teuscher^{158,1}, T. Theveneaux-Pelzer⁸⁶, J. P. Thomas¹⁹, J. Thomas-Wilsker⁷⁸, E. N. Thompson³⁷, P. D. Thompson¹⁹, A. S. Thompson⁵⁵, L. A. Thomsen¹⁷⁵, E. Thomson¹²², M. Thomson³⁰, M. J. Tibbetts¹⁶, R. E. Ticse Torres⁸⁶, V. O. Tikhomirov^{96,ao}, Yu. A. Tikhonov^{109,c}, S. Timoshenko⁹⁸, P. Tipton¹⁷⁵, S. Tisserant⁸⁶, K. Todome¹⁵⁷, T. Todorov^{5,*}, S. Todorova-Nova¹²⁹, J. Tojo⁷¹, S. Tokár^{144a}, K. Tokushuku⁶⁷, E. Tolley⁵⁸, L. Tomlinson⁸⁵, M. Tomoto¹⁰³, L. Tompkins^{143,ap}, K. Toms¹⁰⁵, B. Tong⁵⁸, P. Tornambe⁵⁰, E. Torrence¹¹⁶, H. Torres¹⁴², E. Torró Pastor¹³⁸, J. Toth^{86,aq}, F. Touchard⁸⁶, D. R. Tovey¹³⁹, T. Trefzger¹⁷³, A. Tricoli²⁷, I. M. Trigger^{159a}, S. Trincas-Duvold⁸¹, M. F. Tripiana¹³, W. Trischuk¹⁵⁸, B. Trocme⁵⁷, A. Trofymov⁴⁴, C. Troncon^{92a}, M. Trotter-McDonald¹⁶, M. Trovatelli¹⁶⁸, L. Truong^{163a,163c}, M. Trzebinski⁴¹, A. Trzupek⁴¹, J. C-L. Tseng¹²⁰, P. V. Tsiarshka⁹³, G. Tsipolitis¹⁰, N. Tsirintanis⁹, S. Tsiskaridze¹³, V. Tsiskaridze⁵⁰, E. G. Tskhadadze^{53a}, K. M. Tsui^{61a}, I. I. Tsukerman⁹⁷, V. Tsulaia¹⁶, S. Tsuno⁶⁷, D. Tsybychev¹⁴⁸, Y. Tu^{61b}, A. Tudorache^{28b}, V. Tudorache^{28b}, A. N. Tuna⁵⁸, S. A. Tupputi^{22a,22b}, S. Turchikhin⁶⁶, D. Turecek¹²⁸, D. Turgeman¹⁷¹, R. Turra^{92a,92b}, P. M. Tuts³⁷, M. Tyndel¹³¹, G. Ucchielli^{22a,22b}, I. Ueda¹⁵⁵, M. Ughetto^{146a,146b}, F. Ukegawa¹⁶⁰, G. Unal³², A. Undrus²⁷, G. Unel¹⁶², F. C. Ungaro⁸⁹, Y. Unno⁶⁷, C. Unverdorben¹⁰⁰, J. Urban^{144b}, P. Urquijo⁸⁹, P. Urrejola⁸⁴, G. Usai⁸, L. Vacavant⁸⁶, V. Vacek¹²⁸, B. Vachon⁸⁸, C. Valderanis¹⁰⁰, E. Valdes Santurio^{146a,146b}, N. Valencic¹⁰⁷, S. Valentini^{22a,22b}, A. Valero¹⁶⁶, L. Valery¹³, S. Valkar¹²⁹, J. A. Valls Ferrer¹⁶⁶, W. Van Den Wollenberg¹⁰⁷, P. C. Van Der Deijl¹⁰⁷, H. van der Graaf¹⁰⁷, N. van Eldik¹⁵², P. van Gemmeren⁶, J. Van Nieuwkoop¹⁴², I. van Vulpen¹⁰⁷, M. C. van Woerden³², M. Vanadia^{132a,132b}, W. Vandelli³², R. Vanguri¹²², A. Vaniachine¹³⁰, P. Vankov¹⁰⁷, G. Vardanyan¹⁷⁶, R. Vari^{132a}, E. W. Varnes⁷, T. Varol⁴², D. Varouchas⁸¹, A. Vartapetian⁸, K. E. Varvell¹⁵⁰, J. G. Vazquez¹⁷⁵, G. A. Vazquez^{34b}, F. Vazeille³⁶, T. Vazquez Schroeder⁸⁸, J. Veatch⁵⁶, V. Veeraraghavan⁷, L. M. Veloce¹⁵⁸, F. Veloso^{126a,126c}, S. Veneziano^{132a}, A. Ventura^{74a,74b}, M. Venturi¹⁶⁸, N. Venturi¹⁵⁸, A. Venturini²⁵, V. Vercesi^{121a}, M. Verducci^{132a,132b}, W. Verkerke¹⁰⁷, J. C. Vermeulen¹⁰⁷, A. Vest^{46,ar}, M. C. Vetterli^{142,d}, O. Viazlo⁸², I. Vichou^{165,*}, T. Vickey¹³⁹, O. E. Vickey Boeriu¹³⁹, G. H. A. Viehhauser¹²⁰, S. Viel¹⁶, L. Vigani¹²⁰, M. Villa^{22a,22b}, M. Villaplana Perez^{92a,92b}, E. Vilucchi⁴⁹, M. G. Vinciter³¹, V. B. Vinogradov⁶⁶, C. Vittori^{22a,22b}, I. Vivarelli¹⁴⁹, S. Vlachos¹⁰, M. Vlasak¹²⁸, M. Vogel¹⁷⁴, P. Vokac¹²⁸, G. Volpi^{124a,124b}, M. Volpi⁸⁹, H. von der Schmitt¹⁰¹, E. von Toerne²³, V. Vorobel¹²⁹, K. Vorobev⁹⁸, M. Vos¹⁶⁶, R. Voss³², J. H. Vossebeld⁷⁵, N. Vranjes¹⁴, M. Vranjes Milosavljevic¹⁴, V. Vrba¹²⁷, M. Vreeswijk¹⁰⁷, R. Vuillermet³², I. Vukotic³³, Z. Vykydal¹²⁸, P. Wagner²³, W. Wagner¹⁷⁴, H. Wahlberg⁷², S. Wahrmund⁴⁶, J. Wakabayashi¹⁰³, J. Walder⁷³, R. Walker¹⁰⁰,

W. Walkowiak¹⁴¹, V. Wallangen^{146a,146b}, C. Wang^{35c}, C. Wang^{35d,86}, F. Wang¹⁷², H. Wang¹⁶, H. Wang⁴², J. Wang⁴⁴, J. Wang¹⁵⁰, K. Wang⁸⁸, R. Wang⁶, S. M. Wang¹⁵¹, T. Wang²³, T. Wang³⁷, W. Wang^{35b}, X. Wang¹⁷⁵, C. Wanotayaroj¹¹⁶, A. Warburton⁸⁸, C. P. Ward³⁰, D. R. Wardrope⁷⁹, A. Washbrook⁴⁸, P. M. Watkins¹⁹, A. T. Watson¹⁹, M. F. Watson¹⁹, G. Watts¹³⁸, S. Watts⁸⁵, B. M. Waugh⁷⁹, S. Webb⁸⁴, M. S. Weber¹⁸, S. W. Weber¹⁷³, S. A. Weber³¹, J. S. Webster⁶, A. R. Weidberg¹²⁰, B. Weinert⁶², J. Weingarten⁵⁶, C. Weiser⁵⁰, H. Weits¹⁰⁷, P. S. Wells³², T. Wenaus²⁷, T. Wengler³², S. Wenig³², N. Wermes²³, M. Werner⁵⁰, M. D. Werner⁶⁵, P. Werner³², M. Wessels^{59a}, J. Wetter¹⁶¹, K. Whalen¹¹⁶, N. L. Whallon¹³⁸, A. M. Wharton⁷³, A. White⁸, M. J. White¹, R. White^{34b}, D. Whiteson¹⁶², F. J. Wickens¹³¹, W. Wiedenmann¹⁷², M. Wielers¹³¹, C. Wiglesworth³⁸, L. A. M. Wiik-Fuchs²³, A. Wildauer¹⁰¹, F. Wilk⁸⁵, H. G. Wilkens³², H. H. Williams¹²², S. Williams¹⁰⁷, C. Willis⁹¹, S. Willocq⁸⁷, J. A. Wilson¹⁹, I. Wingerter-Seez⁵, F. Winklmeier¹¹⁶, O. J. Winston¹⁴⁹, B. T. Winter²³, M. Wittgen¹⁴³, J. Wittkowski¹⁰⁰, T. M. H. Wolf¹⁰⁷, M. W. Wolter⁴¹, H. Wolters^{126a,126c}, S. D. Worm¹³¹, B. K. Wosiek⁴¹, J. Wotschack³², M. J. Woudstra⁸⁵, K. W. Wozniak⁴¹, M. Wu⁵⁷, M. Wu³³, S. L. Wu¹⁷², X. Wu⁵¹, Y. Wu⁹⁰, T. R. Wyatt⁸⁵, B. M. Wynne⁴⁸, S. Xella³⁸, D. Xu^{35a}, L. Xu²⁷, B. Yabsley¹⁵⁰, S. Yacoub^{145a}, D. Yamaguchi¹⁵⁷, Y. Yamaguchi¹¹⁸, A. Yamamoto⁶⁷, S. Yamamoto¹⁵⁵, T. Yamanaka¹⁵⁵, K. Yamauchi¹⁰³, Y. Yamazaki⁶⁸, Z. Yan²⁴, H. Yang^{35e}, H. Yang¹⁷², Y. Yang¹⁵¹, Z. Yang¹⁵, W.-M. Yao¹⁶, Y. C. Yap⁸¹, Y. Yasu⁶⁷, E. Yatsenko⁵, K. H. Yau Wong²³, J. Ye⁴², S. Ye²⁷, I. Yeletsikh⁶⁶, A. L. Yen⁵⁸, E. Yildirim⁸⁴, K. Yorita¹⁷⁰, R. Yoshida⁶, K. Yoshihara¹²², C. Young¹⁴³, C. J. S. Young³², S. Youssef²⁴, D. R. Yu¹⁶, J. Yu⁸, J. M. Yu⁹⁰, J. Yu⁶⁵, L. Yuan⁶⁸, S. P. Y. Yuen²³, I. Yusuff^{30,as}, B. Zabinski⁴¹, R. Zaidan⁶⁴, A. M. Zaitsev^{130,ae}, N. Zakharuk⁴⁴, J. Zalieckas¹⁵, A. Zaman¹⁴⁸, S. Zambito⁵⁸, L. Zanello^{132a,132b}, D. Zanzi⁸⁹, A. G. Zecchinelli^{92a,92b}, C. Zeitnitz¹⁷⁴, M. Zeman¹²⁸, A. Zemla^{40a}, J. C. Zeng¹⁶⁵, Q. Zeng¹⁴³, K. Zengel²⁵, O. Zenin¹³⁰, T. Ženis^{144a}, D. Zerwas¹¹⁷, D. Zhang⁹⁰, F. Zhang¹⁷², G. Zhang^{35b,an}, H. Zhang^{35c}, J. Zhang⁶, L. Zhang⁵⁰, R. Zhang²³, R. Zhang^{35b,at}, X. Zhang^{35d}, Z. Zhang¹¹⁷, X. Zhao⁴², Y. Zhao^{35d}, Z. Zhao^{35b}, A. Zhemchugov⁶⁶, J. Zhong¹²⁰, B. Zhou⁹⁰, C. Zhou⁴⁷, L. Zhou³⁷, L. Zhou⁴², M. Zhou¹⁴⁸, N. Zhou^{35f}, C. G. Zhu^{35d}, H. Zhu^{35a}, J. Zhu⁹⁰, Y. Zhu^{35b}, X. Zhuang^{35a}, K. Zhukov⁹⁶, A. Zibell¹⁷³, D. Zieminska⁶², N. I. Zimine⁶⁶, C. Zimmermann⁸⁴, S. Zimmermann⁵⁰, Z. Zinonos⁵⁶, M. Zinser⁸⁴, M. Ziolkowski¹⁴¹, L. Živković¹⁴, G. Zobernig¹⁷², A. Zoccoli^{22a,22b}, M. zur Nedden¹⁷, L. Zwalinski³²

¹ Department of Physics, University of Adelaide, Adelaide, Australia

² Physics Department, SUNY Albany, Albany, NY, USA

³ Department of Physics, University of Alberta, Edmonton, AB, Canada

⁴ (a) Department of Physics, Ankara University, Ankara, Turkey; (b) Istanbul Aydin University, Istanbul, Turkey; (c) Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey

⁵ LAPP, CNRS/IN2P3 and Université Savoie Mont Blanc, Annecy-le-Vieux, France

⁶ High Energy Physics Division, Argonne National Laboratory, Argonne, IL, USA

⁷ Department of Physics, University of Arizona, Tucson, AZ, USA

⁸ Department of Physics, The University of Texas at Arlington, Arlington, TX, USA

⁹ Physics Department, University of Athens, Athens, Greece

¹⁰ Physics Department, National Technical University of Athens, Zografou, Greece

¹¹ Department of Physics, The University of Texas at Austin, Austin, TX, USA

¹² Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹³ Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain

¹⁴ Institute of Physics, University of Belgrade, Belgrade, Serbia

¹⁵ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁶ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, USA

¹⁷ Department of Physics, Humboldt University, Berlin, Germany

¹⁸ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

¹⁹ School of Physics and Astronomy, University of Birmingham, Birmingham, UK

²⁰ (a) Department of Physics, Bogazici University, Istanbul, Turkey; (b) Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey; (c) Faculty of Engineering and Natural Sciences, Istanbul Bilgi University, Istanbul, Turkey; (d) Faculty of Engineering and Natural Sciences, Bahcesehir University, Istanbul, Turkey

²¹ Centro de Investigaciones, Universidad Antonio Narino, Bogotá, Colombia

²² (a) INFN Sezione di Bologna, Bologna, Italy; (b) Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy

²³ Physikalisches Institut, University of Bonn, Bonn, Germany

- ²⁴ Department of Physics, Boston University, Boston, MA, USA
- ²⁵ Department of Physics, Brandeis University, Waltham, MA, USA
- ²⁶ (a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil; (b) Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora, Brazil; (c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei, Brazil; (d) Instituto de Fisica, Universidade de Sao Paulo, São Paulo, Brazil
- ²⁷ Physics Department, Brookhaven National Laboratory, Upton, NY, USA
- ²⁸ (a) Transilvania University of Brasov, Brasov, Romania; (b) National Institute of Physics and Nuclear Engineering, Bucharest, Romania; (c) Physics Department, National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj Napoca, Romania; (d) University Politehnica Bucharest, Bucharest, Romania; (e) West University in Timisoara, Timisoara, Romania
- ²⁹ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- ³⁰ Cavendish Laboratory, University of Cambridge, Cambridge, UK
- ³¹ Department of Physics, Carleton University, Ottawa, ON, Canada
- ³² CERN, Geneva, Switzerland
- ³³ Enrico Fermi Institute, University of Chicago, Chicago, IL, USA
- ³⁴ (a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile; (b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- ³⁵ (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China; (b) Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui, China; (c) Department of Physics, Nanjing University, Nanjing, Jiangsu, China; (d) School of Physics, Shandong University, Jinan, Shandong, China; (e) Shanghai Key Laboratory for Particle Physics and Cosmology, Department of Physics and Astronomy, Shanghai Jiao Tong University (also affiliated with PKU-CHEP), Shanghai, China; (f) Physics Department, Tsinghua University, Beijing 100084, China
- ³⁶ Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France
- ³⁷ Nevis Laboratory, Columbia University, Irvington, NY, USA
- ³⁸ Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- ³⁹ (a) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Frascati, Italy; (b) Dipartimento di Fisica, Università della Calabria, Rende, Italy
- ⁴⁰ (a) Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Kraków, Poland; (b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland
- ⁴¹ Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
- ⁴² Physics Department, Southern Methodist University, Dallas, TX, USA
- ⁴³ Physics Department, University of Texas at Dallas, Richardson, TX, USA
- ⁴⁴ DESY, Hamburg and Zeuthen, Hamburg, Germany
- ⁴⁵ Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- ⁴⁶ Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
- ⁴⁷ Department of Physics, Duke University, Durham, NC, USA
- ⁴⁸ SUPA-School of Physics and Astronomy, University of Edinburgh, Edinburgh, UK
- ⁴⁹ INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ⁵⁰ Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany
- ⁵¹ Section de Physique, Université de Genève, Geneva, Switzerland
- ⁵² (a) INFN Sezione di Genova, Genoa, Italy; (b) Dipartimento di Fisica, Università di Genova, Genoa, Italy
- ⁵³ (a) E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia; (b) High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- ⁵⁴ II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- ⁵⁵ SUPA-School of Physics and Astronomy, University of Glasgow, Glasgow, UK
- ⁵⁶ II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- ⁵⁷ Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
- ⁵⁸ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, USA
- ⁵⁹ (a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany; (b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany; (c) ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- ⁶⁰ Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan

- ⁶¹ (a)Department of Physics, The Chinese University of Hong Kong, Shatin, NT, Hong Kong; (b)Department of Physics, The University of Hong Kong, Hong Kong, China; (c)Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
- ⁶² Department of Physics, Indiana University, Bloomington, IN, USA
- ⁶³ Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- ⁶⁴ University of Iowa, Iowa City, IA, USA
- ⁶⁵ Department of Physics and Astronomy, Iowa State University, Ames, IA, USA
- ⁶⁶ Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- ⁶⁷ KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- ⁶⁸ Graduate School of Science, Kobe University, Kobe, Japan
- ⁶⁹ Faculty of Science, Kyoto University, Kyoto, Japan
- ⁷⁰ Kyoto University of Education, Kyoto, Japan
- ⁷¹ Department of Physics, Kyushu University, Fukuoka, Japan
- ⁷² Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- ⁷³ Physics Department, Lancaster University, Lancaster, UK
- ⁷⁴ (a)INFN Sezione di Lecce, Lecce, Italy; (b)Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
- ⁷⁵ Oliver Lodge Laboratory, University of Liverpool, Liverpool, UK
- ⁷⁶ Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- ⁷⁷ School of Physics and Astronomy, Queen Mary University of London, London, UK
- ⁷⁸ Department of Physics, Royal Holloway University of London, Surrey, UK
- ⁷⁹ Department of Physics and Astronomy, University College London, London, UK
- ⁸⁰ Louisiana Tech University, Ruston, LA, USA
- ⁸¹ Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- ⁸² Fysiska institutionen, Lunds universitet, Lund, Sweden
- ⁸³ Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
- ⁸⁴ Institut für Physik, Universität Mainz, Mainz, Germany
- ⁸⁵ School of Physics and Astronomy, University of Manchester, Manchester, UK
- ⁸⁶ CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- ⁸⁷ Department of Physics, University of Massachusetts, Amherst, MA, USA
- ⁸⁸ Department of Physics, McGill University, Montreal, QC, Canada
- ⁸⁹ School of Physics, University of Melbourne, Melbourne, VIC, Australia
- ⁹⁰ Department of Physics, The University of Michigan, Ann Arbor, MI, USA
- ⁹¹ Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA
- ⁹² (a)INFN Sezione di Milano, Milan, Italy; (b)Dipartimento di Fisica, Università di Milano, Milan, Italy
- ⁹³ B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
- ⁹⁴ National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
- ⁹⁵ Group of Particle Physics, University of Montreal, Montreal, QC, Canada
- ⁹⁶ P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
- ⁹⁷ Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- ⁹⁸ National Research Nuclear University MEPhI, Moscow, Russia
- ⁹⁹ D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
- ¹⁰⁰ Fakultät für Physik, Ludwig-Maximilians-Universität München, Munich, Germany
- ¹⁰¹ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Munich, Germany
- ¹⁰² Nagasaki Institute of Applied Science, Nagasaki, Japan
- ¹⁰³ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- ¹⁰⁴ (a)INFN Sezione di Napoli, Naples, Italy; (b)Dipartimento di Fisica, Università di Napoli, Naples, Italy
- ¹⁰⁵ Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, USA
- ¹⁰⁶ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, The Netherlands
- ¹⁰⁷ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, The Netherlands
- ¹⁰⁸ Department of Physics, Northern Illinois University, DeKalb, IL, USA
- ¹⁰⁹ Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia

- ¹¹⁰ Department of Physics, New York University, New York, NY, USA
- ¹¹¹ Ohio State University, Columbus, OH, USA
- ¹¹² Faculty of Science, Okayama University, Okayama, Japan
- ¹¹³ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, USA
- ¹¹⁴ Department of Physics, Oklahoma State University, Stillwater, OK, USA
- ¹¹⁵ Palacký University, RCPTM, Olomouc, Czech Republic
- ¹¹⁶ Center for High Energy Physics, University of Oregon, Eugene, OR, USA
- ¹¹⁷ LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
- ¹¹⁸ Graduate School of Science, Osaka University, Osaka, Japan
- ¹¹⁹ Department of Physics, University of Oslo, Oslo, Norway
- ¹²⁰ Department of Physics, Oxford University, Oxford, UK
- ¹²¹ (a) INFN Sezione di Pavia, Pavia, Italy; (b) Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- ¹²² Department of Physics, University of Pennsylvania, Philadelphia, PA, USA
- ¹²³ National Research Centre “Kurchatov Institute” B.P. Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia
- ¹²⁴ (a) INFN Sezione di Pisa, Pisa, Italy; (b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- ¹²⁵ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, USA
- ¹²⁶ (a) Laboratório de Instrumentação e Física Experimental de Partículas-LIP, Lisbon, Portugal; (b) Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal; (c) Department of Physics, University of Coimbra, Coimbra, Portugal; (d) Centro de Física Nuclear da Universidade de Lisboa, Lisbon, Portugal; (e) Departamento de Física, Universidade do Minho, Braga, Portugal; (f) Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain; (g) Dep Física and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
- ¹²⁷ Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
- ¹²⁸ Czech Technical University in Prague, Prague, Czech Republic
- ¹²⁹ Faculty of Mathematics and Physics, Charles University in Prague, Prague, Czech Republic
- ¹³⁰ State Research Center Institute for High Energy Physics (Protvino), NRC KI, Protvino, Russia
- ¹³¹ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, UK
- ¹³² (a) INFN Sezione di Roma, Rome, Italy; (b) Dipartimento di Fisica, Sapienza Università di Roma, Rome, Italy
- ¹³³ (a) INFN Sezione di Roma Tor Vergata, Rome, Italy; (b) Dipartimento di Fisica, Università di Roma Tor Vergata, Rome, Italy
- ¹³⁴ (a) INFN Sezione di Roma Tre, Rome, Italy; (b) Dipartimento di Matematica e Fisica, Università Roma Tre, Rome, Italy
- ¹³⁵ (a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies-Université Hassan II, Casablanca, Morocco; (b) Centre National de l’Energie des Sciences Techniques Nucleaires, Rabat, Morocco; (c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Marrakech, Morocco; (d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco; (e) Faculté des Sciences, Université Mohammed V, Rabat, Morocco
- ¹³⁶ DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat à l’Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France
- ¹³⁷ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, USA
- ¹³⁸ Department of Physics, University of Washington, Seattle, WA, USA
- ¹³⁹ Department of Physics and Astronomy, University of Sheffield, Sheffield, UK
- ¹⁴⁰ Department of Physics, Shinshu University, Nagano, Japan
- ¹⁴¹ Fachbereich Physik, Universität Siegen, Siegen, Germany
- ¹⁴² Department of Physics, Simon Fraser University, Burnaby, BC, Canada
- ¹⁴³ SLAC National Accelerator Laboratory, Stanford, CA, USA
- ¹⁴⁴ (a) Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic; (b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- ¹⁴⁵ (a) Department of Physics, University of Cape Town, Cape Town, South Africa; (b) Department of Physics, University of Johannesburg, Johannesburg, South Africa; (c) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- ¹⁴⁶ (a) Department of Physics, Stockholm University, Stockholm, Sweden; (b) The Oskar Klein Centre, Stockholm, Sweden

- ¹⁴⁷ Physics Department, Royal Institute of Technology, Stockholm, Sweden
 - ¹⁴⁸ Departments of Physics and Astronomy and Chemistry, Stony Brook University, Stony Brook, NY, USA
 - ¹⁴⁹ Department of Physics and Astronomy, University of Sussex, Brighton, UK
 - ¹⁵⁰ School of Physics, University of Sydney, Sydney, Australia
 - ¹⁵¹ Institute of Physics, Academia Sinica, Taipei, Taiwan
 - ¹⁵² Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel
 - ¹⁵³ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
 - ¹⁵⁴ Department of Physics, Aristotle University of Thessaloniki, Thessaloníki, Greece
 - ¹⁵⁵ International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
 - ¹⁵⁶ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
 - ¹⁵⁷ Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
 - ¹⁵⁸ Department of Physics, University of Toronto, Toronto, ON, Canada
 - ¹⁵⁹ (a) TRIUMF, Vancouver, BC, Canada; (b) Department of Physics and Astronomy, York University, Toronto, ON, Canada
 - ¹⁶⁰ Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba, Tsukuba, Japan
 - ¹⁶¹ Department of Physics and Astronomy, Tufts University, Medford, MA, USA
 - ¹⁶² Department of Physics and Astronomy, University of California Irvine, Irvine, CA, USA
 - ¹⁶³ (a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy; (b) ICTP, Trieste, Italy; (c) Dipartimento di Chimica Fisica e Ambiente, Università di Udine, Udine, Italy
 - ¹⁶⁴ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
 - ¹⁶⁵ Department of Physics, University of Illinois, Urbana, IL, USA
 - ¹⁶⁶ Instituto de Física Corpuscular (IFIC) and Departamento de Física Atomica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
 - ¹⁶⁷ Department of Physics, University of British Columbia, Vancouver, BC, Canada
 - ¹⁶⁸ Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
 - ¹⁶⁹ Department of Physics, University of Warwick, Coventry, UK
 - ¹⁷⁰ Waseda University, Tokyo, Japan
 - ¹⁷¹ Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
 - ¹⁷² Department of Physics, University of Wisconsin, Madison, WI, USA
 - ¹⁷³ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
 - ¹⁷⁴ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
 - ¹⁷⁵ Department of Physics, Yale University, New Haven, CT, USA
 - ¹⁷⁶ Yerevan Physics Institute, Yerevan, Armenia
 - ¹⁷⁷ Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France
- ^a Also at Department of Physics, King's College London, London, United Kingdom
- ^b Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ^c Also at Novosibirsk State University, Novosibirsk, Russia
- ^d Also at TRIUMF, Vancouver BC, Canada
- ^e Also at Department of Physics & Astronomy, University of Louisville, Louisville, KY, United States of America
- ^f Also at Department of Physics, California State University, Fresno CA, United States of America
- ^g Also at Department of Physics, University of Fribourg, Fribourg, Switzerland
- ^h Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain
- ⁱ Also at Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Portugal
- ^j Also at Tomsk State University, Tomsk, Russia
- ^k Also at Università di Napoli Parthenope, Napoli, Italy
- ^l Also at Institute of Particle Physics (IPP), Canada
- ^m Also at National Institute of Physics and Nuclear Engineering, Bucharest, Romania
- ⁿ Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia
- ^o Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- ^p Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa

- ^q Also at Louisiana Tech University, Ruston LA, United States of America
- ^r Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain
- ^s Also at Graduate School of Science, Osaka University, Osaka, Japan
- ^t Also at Department of Physics, National Tsing Hua University, Taiwan
- ^u Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- ^v Also at Department of Physics, The University of Texas at Austin, Austin TX, United States of America
- ^w Also at CERN, Geneva, Switzerland
- ^x Also at Georgian Technical University (GTU), Tbilisi, Georgia
- ^y Also at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan
- ^z Also at Manhattan College, New York NY, United States of America
- ^{aa} Also at Hellenic Open University, Patras, Greece
- ^{ab} Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{ac} Also at School of Physics, Shandong University, Shandong, China
- ^{ad} Also at Department of Physics, California State University, Sacramento CA, United States of America
- ^{ae} Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia
- ^{af} Also at Section de Physique, Université de Genève, Geneva, Switzerland
- ^{ag} Also at Eotvos Lorand University, Budapest, Hungary
- ^{ah} Also at Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
- ^{ai} Also at International School for Advanced Studies (SISSA), Trieste, Italy
- ^{aj} Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- ^{ak} Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
- ^{al} Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria
- ^{am} Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
- ^{an} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{ao} Also at National Research Nuclear University MEPhI, Moscow, Russia
- ^{ap} Also at Department of Physics, Stanford University, Stanford CA, United States of America
- ^{aq} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
- ^{ar} Also at Flensburg University of Applied Sciences, Flensburg, Germany
- ^{as} Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia
- ^{at} Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- * Deceased